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p71

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Future of Technology
June 2011
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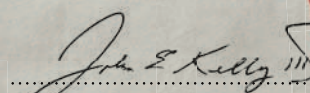
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Accelerating Software Modernization with Artificial Intelligence

AI is radically transforming the way organizations evolve their software assets to achieve competitive advantage.

Artificial Intelligence (AI) is the quest to achieve computers that equal or exceed human performance on complex intellectual tasks. A phenomenal development in AI is the recent emergence of automated computer language translation programs, driven by the need to modernize the nearly half trillion lines of legacy software developed during the latter half of the 20th century.

Early software translators of the 1990s, like the earliest chess programs, were disappointing and limited. Leveraging AI technologies that evolved from the 1980s era USAF's Knowledge Based Software Assistant and emerging standards, computers can now understand and translate software applications with levels of proficiency that vastly exceed human performance. This technology is revolutionizing the way industries, such as finance, insurance, manufacturing, and healthcare as well as military and governments are modernizing their legacy systems.

Leading this field is The Software Revolution, Inc. (TSRI), a Kirkland, Washington based company. Building upon 32 years of continuous R&D, TSRI's robust JANUS Studio® tool suite provides large-scale, error-free legacy system modernizations at 100% levels of automation. By applying AI to abstract software models, TSRI delivers automated code conversion with unprecedented target code quality, economies of scale and schedule compression, accomplishing with small teams in months what would take years by other means. The following list of brief case studies represents five recent TSRI legacy system modernization projects.

• **European Air Traffic Management System (EATMS), Thales Air Systems:** This realtime system manages over 10 million passenger flights annually. Thales engaged TSRI to



transform EUROCAT's 2 million lines of legacy Ada into Java. The result was a perfect functional replica of EUROCAT in its new language. TSRI's 100% automation eliminated the risk of errors inherent in a manual rewrite. EUROCAT will commence operation in significant airports across Europe and Asia at the end of 2011.

• **Patriot Missile, Fire Platoon Simulation & Battalion Simulation Support Systems, Raytheon:** TSRI used the JANUS Studio® tool suite to modernize four different Patriot systems including Patriot Japan. These modernizations included the transformation of nearly 200 thousand source lines of Fortran code to C++, re-factoring and documentation.

• **Major Healthcare Insurance Company:** This system consisted of over 180 thousand source lines of PowerBuilder and nearly 3 million lines of COBOL. In modernizing this system TSRI provided transformation, re-factoring and supported system integration. This project was completed in only 15 months.

• **Major US Bank:** This legacy application contained over 3 million source lines of Fortran and over 160 thousand lines of DCL. TSRI automatically generated a *Transformation Blueprint™* to assist in the systems design architecture, performed the code documentation and provided engineering support.

• **Advanced Field Artillery Tactical Data System (AFATDS), Stanley and Associates (Now CGI Federal):** A version of the US Army's legacy AFATDS system consisting of over 5 million source lines of ADA-83. TSRI employed JANUS Studio® to transform this system into Java in only 10 months. TSRI delivered the modern system to Stanley in August 2010.

Information Systems Transformation: *Architecture-Driven Modernization Case Studies* provides more detailed information on these case studies.

For more information visit www.tsri.com



Information Systems Transformation:
Architecture-Driven Modernization Case Studies
By William M. Ulrich and Philip Newcomb
ISBN: 978-0123749130

About the book:
Architecture-Driven Modernization (ADM) gives you everything you need to know to update costly obsolete systems, transform data, and save millions of dollars.

Philip Newcomb
Founder and CEO of TSRI

Mr. Newcomb is an internationally recognized expert in the application of AI and formal methods to software engineering. After leaving Boeing he led a team of software engineers to develop TSRI's JANUS Studio® tool suite. Mr. Newcomb is the author of numerous papers, books and industry standards.



TSRI is a Platform Member of the OMG and leading contributor to the ADM Task Force (ADMTF) standards. TSRI's services and JANUS Studio® tool suite have served as the leading exemplar for the OMG's emerging ADMTF standards.



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Accelerating Legacy Modernization



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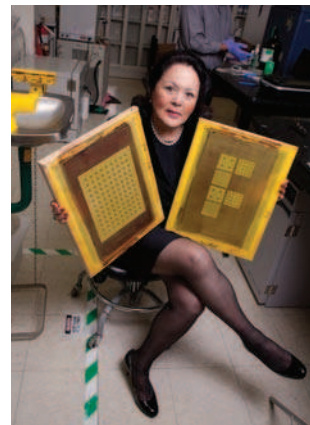
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Now we're talking private cloud, not just virtualization.


Windows Server is changing
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Windows Server Hyper-V and System Center let you manage your infrastructure as a private cloud: a pool of computing resources that lets you allocate computing power to your applications as your business requires. And Microsoft provides common management, identity and development tools that work across your infrastructure. End-to-end control. Agility beyond virtualization. **That's Cloud Power.**

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THE ROLE OF WIKILEAKS

Thank you for your truly spot-on column examining the impact of WikiLeaks on society's concept of secrecy and transparency ("Is WikiLeaks a Good Thing?" March/April 2011). Like you, I often find myself conflicted about the value of WikiLeaks. I tend to eschew overt calls for full disclosure from organizations—whether by government leaders, executives, or individuals pushing a cause—because my first inclination is to uphold the right to privacy. However, instances in the past year throughout the global business community have begun to change my mind. And as the associate director of public relations for the Public Relations Society of America, I am committed to transparency and disclosure in all forms of communication to advance the free flow of accurate and truthful information, which is vital to democratic societies. While WikiLeaks may take corporate transparency too far for some, numerous surveys have revealed that trust in American businesses and government is terribly low. Perhaps it is time to look past the potentially sinister goals of Julian Assange and WikiLeaks and develop a more earnest commitment to withholding only information that truly deserves secrecy.

Keith Trivitt

New York

I am very puzzled by your assertion that you distrust transparency. You state that you are "wary of attacks" upon the institutions of a "properly constituted state." Why would you equate a desire to have those institutions be transparent with an

"attack"? In the Western European tradition of corporate governance (especially Germany's "codetermination" laws), corporations have responsibilities not only to their owners and stockholders, but also to their employees and the societies at large within which they operate. Just as anonymity encourages bad behavior among individuals, secrecy in institutions breeds lies, corruption, and, ultimately, tyranny.

Claus Gehner

Seattle

NEED FOR SPEED

"The Slow-Motion Internet" (March/April 2011) highlighted the ways that a site or Web-based app can get bogged down on its way to the end user. Of all these, front-end issues—defined as how the browser handles code—account for roughly 90 percent of all performance problems. As a result, while Google's performance-related initiatives are inspiring, and will contribute somewhat to a faster Internet, the onus for delivering a faster experience mainly rests on website owners. Web content optimization, which transforms each page so that it can be rendered optimally for each browser type, is a powerful solution. (Disclosure: My company offers such solutions to websites.)

Joshua Bixby

President, Strangeloop

Vancouver, British Columbia

The development and adoption of new protocols and an overhaul of the fundamental anatomy of the Web is going to take a very long time. If we're going to noticeably improve Web performance right now, and usher in a world where the browser truly becomes the OS, we need to take a hard look at the way that we code and develop Web apps and media-rich websites and optimize them for better performance

within the constraints of today's Web. As the CEO of Aptimize, I like to say it's a lot like the choice between drilling for more oil and building more efficient cars. The smart choice is to pursue both solutions.

Ed Robinson

Wellington, New Zealand

TOO MANY SCANS

I'm appalled to read Jonathan Rothberg saying, "Patients will be just as likely

to have their genomes sequenced as they will be to get MRIs or CT scans" (Q&A, March/April 2011). There are already thousands of unnecessary MRI and CT scans, as well as other tests, being done at great cost to taxpayers who support Medicare and to purchasers of private medical insurance, with little or no positive patient benefits. Genome sequencing will add one

more money sinkhole! Our medical system has major problems, including our unwillingness to analyze the probability of a net positive patient outcome for each of these expensive procedures. Until we do that, the advent of genome sequencing will just add to runaway costs.

Mark R. Pratt

Naples, Florida

ENERGY SOLUTIONS

I think the word "breakthrough" has been overused ("Praying for an Energy Miracle," March/April 2011). What we need is a solution. Wind and solar schemes are not "affordable electricity" and are unreliable and nondispatchable. The missing "breakthrough" is clean, affordable electricity (about seven cents per kilowatt-hour). The U.S. Department of Energy should offer a \$1 billion prize for that missing breakthrough. Less-than-mediocre clean energy schemes are wasting billions on development deals



March/April 2011

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when they will not solve our energy problem. A prize might.

*Andrew West
San Francisco*

Solar's key feature is local generation. All traditional fuels—natural gas, coal, even hydro—assume a functioning grid. There are lots of places, many in the U.S., where grid access is totally absent, poorly maintained, or vulnerable to disruption. These regions are where solar will put down roots and go through the long-term development needed to compete with hydrocarbons.

*Fred Hapgood
Boston*

APPS VS. THE WEB

Håkon Wium Lie ("Web Wins," March/April 2011) concludes that native apps will become "a footnote" in computing history. Native applications have been the norm for decades on personal computers, and native software has dominated on mobile devices. Even if most apps do become Web-based in the future, calling this long history a footnote borders on the absurd.

*Robin Stewart
Seattle*

WILL SQUARE SAVE PEOPLE MONEY?

Charging 2.75 percent plus 15 cents? Ouch. I'm amazed credit card companies took so much money ("The New Money," March/April 2011). Imagine if all transactions were through Square and they could sit back with more than 2.75 percent of GDP pumping in!

*Oren Robinson
Auckland, New Zealand*

Be thankful it's only 2 percent—it used to be 5 to 6 percent. Banks charge much more to set up a regular merchant account, so that's why PayPal is such a good deal for online stores. You don't need special software, and the fees are reasonable.

*Carl Hage
Sunnyvale, California*

Can semantic technologies make the Web truly worldwide?

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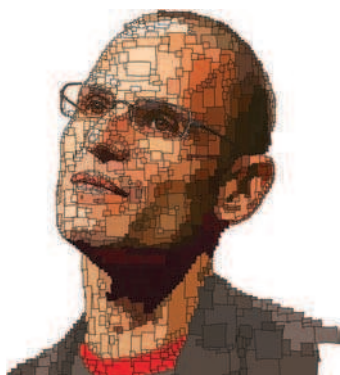


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MOBILE DEVICES

Smarter Phones

High-powered handsets offer few advantages for the developing world, says Robert Fabricant.

It is an article of faith in technological circles that the smart phone will become the dominant personal device around the world within the next decade. After all, smart-phone shipments surpassed PC shipments in 2010 (*see Briefing*, p. 71). How long before we see a device comparable to a first-generation iPhone or Droid for emerging markets?

Smart phones are already arriving in some parts of the developing world. When I visited Tanzania last May, for example, I was shocked by the number of advertisements for BlackBerry; I even saw them on passport control booths on my way out of the country. Members of the urban elite in Africa seem to be following directly in our footsteps, to the delight of smart-phone makers like RIM, Google, and Apple.

Yet after spending extensive time in Africa conducting ethnographic research, I am beginning to worry that for the majority of the world's population, smart

phones may actually be a move in the wrong direction. There is much to be learned instead from the innovative uses to which basic, "outdated" mobile phones are being put in this broad, underserved market. The Kenyan mobile banking service M-Pesa, for example, is driving a mobile revolution in banking. But it didn't become popular because of touch screens and mobile apps.

When devices can handle only voice calls and text messaging, services must be simple, efficient, accessible, and affordable. That makes them broadly useful for large numbers of people. Legions of dedicated apps, by contrast, force functionality, information, and users into silos.

The most successful consumer technology in the developing world—radio—demonstrates the power of spreading information widely and efficiently. Bulk text-messaging services like SMSall in Pakistan are some of the most important innovations in international development over the last decade. Accessible from any handset, they support group coordination and community awareness.

Mobile devices in the developing world are shared resources, not personal computers used by a single person, as the smart-phone model assumes. One phone may be used by a whole family—or a whole community where an entrepreneur offers phone services. Pursuing the path to increasingly beautiful (and expensive) personal gadgets simply does not serve these people's interests. Instead, they need their mobile identities to be freed from hardware.

This is a radical shift for companies seeking new audiences in the developing world, but it can be done. At Frog, we have been working with a startup called Movirtu on a technology that allows people to use any handset to access their personal information. Now, why can't my iPhone or Droid do that?

Touch screens can certainly improve the user experience, but in many poten-

tial markets, hardware and apps may be beside the point. Separating mobile services from specific advances in hardware can unlock tremendous value. The sooner we do this, the better.

ROBERT FABRICANT IS VICE PRESIDENT OF CREATIVE AT FROG DESIGN, WHERE HE LEADS EFFORTS TO EXPAND THE IMPACT OF DESIGN INTO NEW MARKETS AND INDUSTRIES.

INNOVATION

Forecasting Futures

Brad Feld explains how to spot emerging technologies that will change the world.

Since 1994 and the dawn of the commercial Internet, I've been a venture capitalist constantly looking for the next wave of disruptive innovation. In the process, I've developed several deeply held beliefs about how to explore and identify significant new technologies. *Technology Review's* editors used their own methods to pick this issue's TR10 (*see p. 41*), but here's what I do.

My first principle is that you must try to live with any field of innovation you think is important. You must be a user of any and all technology. I'm an early adopter by nature, but I focus extra energy on any new area I am exploring professionally. About a year ago I became obsessed with the idea that humans would be fully instrumented—down to the cellular level—within a decade. For six months I bought and tried a huge range of devices that collect data about the body: electronic sleep coaches, scales that connect to Wi-Fi, a variety of medical devices. This experience eventually led me to invest in a company, FitBit, that is laying the groundwork for a time when we routinely instrument ourselves to collect and analyze data about our lives.

Although I'm a participant in the ecosystem that creates innovation, I'm not

NICK REDDYHOFF



the source of any fundamental technology. Instead, I seek out and spend time with people who are. Curating and attending conferences on emerging technological issues has helped connect me with the amazing people creating the innovations I'm interested in.

I'm not too bashful to ask those people about stuff I don't understand. I understand the value of building up deep knowledge that can be applied to the areas I invest in. I also spend a lot of time reading about technologies so that I can build even deeper knowledge.

It is important, though, not to focus only on technology that already exists. A valuable guide can often be found in science fiction, which has a track record of turning into science fact. Don't limit yourself to futuristic books about space travel, either. What I call "science fiction history"—books written in the past about what our own world would look like today—can provide very useful insight. The notion of cyberspace laid out in William Gibson's 1984 book *Neuromancer* and the "metaverse" described in Neal Stephenson's 1992 novel *Snow Crash* are two examples of fictional virtual worlds that in many ways became reality years later.

Finally, remember that great innovators don't understand the phrase "that's not possible"—and neither do great investors. Make sure you allow yourself to dream about what the future might be like. Even though you must retain a grasp on reality, keep your mind open to

anything. Amazing innovations are being created everywhere, all the time, by obvious—and not so obvious—people.

BRAD FELD IS A MANAGING DIRECTOR OF THE FOUNDRY GROUP, AN EARLY-STAGE VENTURE INVESTOR THAT SPECIALIZES IN INTERNET AND SOFTWARE STARTUPS.

MATERIALS

Rare Talents

Metals crucial to electronics are in short supply, says Karl Gschneidner, and so are the skills needed to solve the problem.

The current shortage of rare-earth elements has made it clear that our ability to create new consumer electronics, develop clean energy technologies, and even maintain the nation's military strength depends on developing a domestic industry to mine and process these materials. But the United States is suffering from more than just a shortage of mining and processing facilities (see "*The Rare-Earth Crisis*," p. 58). Right now, the country lacks the technically trained scientists and engineers required to bring the rare-earth industry back up to speed.

At its height, the industry employed about 25,000 people, approximately 4,000 of whom had college degrees in a science or engineering field. Today the total number is around 1,500, only 250 of whom are college-trained scientists or engineers. And while it may take only a couple of years to restart the nation's rare-earth mines, it will take at least five to 10 years to educate the next generation of "rare-earthers" who must staff the total supply chain from mines to product manufacturers.

The area that will require the largest number of newly trained people is the manufacturing of products that contain rare-earth elements. These products include phosphors for lighting and displays as well as magnets for electric

motors, wind turbines, cell phones, and computers. A smaller number of scientists and engineers will be needed to process the elements into the metals that go into magnets and batteries or into the compounds required for phosphors and catalysts. Still others will be needed to explore for sources of ore and to work in mining.

I estimate that meeting our present need for trained personnel will require graduating about 170 students from PhD, master's, and bachelor's programs each year for four years. Each year after that, we will need between 60 and 100 students



with a solid background in rare earths and the fundamentals of chemistry, materials science, and engineering. The only realistic way for the United States to meet that goal and restart its rare-earth industry is to establish a dedicated national research center at a college or university with a long tradition in the study of what has become a largely forgotten area of science and engineering.

The industry's only real alternative is to turn to China, which is already training hundreds of students in this field. But that would simply re-create the problem we are struggling with: relying on others for such a crucial part of our technological infrastructure.

KARL A. GSCHNEIDNER JR. IS A SENIOR METALLURGIST AT THE U.S. DEPARTMENT OF ENERGY'S AMES LABORATORY AND A PROFESSOR AT THE DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING AT IOWA STATE UNIVERSITY.

Hard Problems, Elegant Solutions, Big Impact

How we choose the “10 Emerging Technologies.”



Every year, *Technology Review* selects the 10 emerging technologies we think have the greatest potential to transform the world. Judging by Web traffic and by newsstand sales of the printed magazine, it is one of our most popular recurring features. But while readers like the 10 technologies, I don’t know if they always understand our choices.

The most common question I receive from readers about the “10 Emerging Technologies” issue is “How do you choose the technologies?” (Among the next-most-frequently-asked questions is “Why didn’t you choose *my* technology?” or “How can I get you to choose my technology next year?” or something of the kind.)

We look first for difficulty. We are interested in hard problems whose solutions would expand human possibilities—or, to consider things from a more negative perspective, whose intractability is a source of frustration or grief.

This year, for instance, we looked at the problem biologists have faced in trying to make large enough pieces of DNA to create an entire genome: “though living cells routinely make long stretches of DNA, a DNA synthesis machine can’t do the same,” writes Katherine Bourzac, *Technology Review*’s materials science editor, in “Synthetic Cells” (p. 56). If biologists could create entire genomes, they could design artificial microbes engineered to produce biofuels, drugs, or other useful products. Daniel Gibson of the J. Craig Venter Institute solved the problem by using yeast cells to stitch together thousands of fragments of DNA made by a machine, and then pooling the longer pieces and repeating the process until he had a complete genome. The result: bacteria that possess the first completely artificial genome.

Next, we look for elegant solutions to interesting problems. Consider the insecurity of cloud computing.

Cloud computing, a technology that lets organizations use the Internet to share computer resources such as applications and storage, is the next great sea change for computing, following personal computing and client-server computing. But organizations are wary of using the cloud for many serious purposes because they feel that giving a public cloud provider such as Amazon or Google access to unencrypted data poses too much of a security risk. It’s possible to send data to and from a cloud provider’s servers in encrypted form, but then the servers that

power the cloud can’t work on that data. Now Craig Gentry at IBM has found a way to analyze data without decrypting it. The trick, explains Erica Naone, our Web and social-networking editor, is “to encrypt the data in such a way that performing a mathematical operation on the encrypted information and then decrypting the result produces the same answer as performing an analogous operation on the unencrypted data” (“*Homomorphic Encryption*,” p. 50). A neat hack. Such correspondence could make enterprise applications secure on the Internet.

Finally, we look for emerging technologies that will have a major impact on business and society over the next decade.

A major emerging trend in social technology is “social indexing.” Most Web users will be familiar with the “Like” button, but they may not be aware that the “likes” of Facebook’s millions of users provide signals about what is valuable online. Bret Taylor, chief technology officer at Facebook, is leading efforts to use that information to make the Web smarter. In “Social Indexing” (p. 42), Tom Simonite, *Technology Review*’s information technology editor, writes, “Many sites have tried to personalize what they offer by remembering your past behavior and showing information they presume will be relevant to you.” Social indexing is potentially more powerful, because it recalls not only your preferences but your friends’ preferences, and over many different sites. The technology is important because it is so different from what we’ve grown accustomed to believing is the organizing principle of the Web: Google’s index, which counts the links between Web pages to gauge their merit. Social indexing will not replace search as the way we use the Web, but it will supplement it, and it will have an enormous social impact because it will tend to strengthen the already prevalent inclination of many Web users to focus on things similar to the things they and their friends have already seen.

This short explanation of how we select our 10 emerging technologies emphasizes what you already suspect: any list of a year’s leading technologies is necessarily partial and subjective. Our list, curated by senior editor Stephen Cass, represents our biases and emphases; you may consider other problems more important, prefer different solutions, and look for impact elsewhere. Write to me and tell me what new technologies you think are the best at jason.pontin@technologyreview.com.

—Jason Pontin

MARK OSTROW

SPAIN ON THE FAST TRACK

HIGH-SPEED TRAIN AND TRANSIT INNOVATION

HIGH-SPEED TRANSPORTATION

The Madrid to Barcelona high-speed rail line opened in early 2008, and traverses 390 miles in only two hours and 38 minutes. In its first year, the line captured more than 50 percent of the travel between the country's two major economic centers, and significantly reduced the number of daily flights between the cities. Since then, Spain's rail authority has continued expanding the network, in 2010 completing the connection between Madrid and the coastal city of Valencia.

Joaquín Jiménez, the director of international relations for Spain's rail administration (the Spanish acronym is ADIF), highlights the fact that Spain has more than 900 miles of high-speed rail under construction or in the planning process. "Developing high-speed rail remains a main objective in Spain," says Jiménez.

According to Michael Clausecker, director of UNIFE, Spain has the most modern fleet of high-speed trains in Europe. The country has also been the first to have its high-speed network fully equipped with the latest signaling system, ERTMS, which will eventually become the unique signaling system for the entire European high-speed system and its international rail corridors, facilitating greater interoperability among different countries.

Spain and France are linking their two countries with a new high-speed line between Perpignan and Barcelona, which will dramatically reduce cross-border travel time. The engineering company Sener was involved in designing this line; despite the relatively short distance, the firm encountered a number of complications, among which were reconciling the two different control systems and two different electrification standards.

"We are living in a very important moment in the development of railways," says Ignacio Barron, director of the high-speed department of the International Union of Railways. He compares today's high-speed expansion to the original expansion of rail in the second half of the 1800s: "These developments are being prepared not only for us today; in fact we are preparing transportation for our children."

As high-speed trains become more common around the world, the companies that sell those trains continue to do research to improve them, says Barron: They're focusing on minimizing noise, lowering the cost of maintenance, and reducing the maximum load to make trains lighter, more aerodynamic, and more energy efficient.

These goals also motivate Spain's train manufacturing company CAF, where engineers at its three-story R&D center devote them-



PHOTO COURTESY OF CAF

Thanks to the continuing growth of its high-speed rail network, Spain now holds first place in Europe and second place in the world (behind only China) for mileage of high-speed tracks. And improvements to the Madrid and Barcelona subways have given those cities two of the most advanced and comprehensive metro systems in Europe, even in the world, according to Michael Clausecker, director of UNIFE, the Association of the European Rail Industry.

Spanish companies and local governments have taken their experience to other countries as well, providing services to cities and countries that are inaugurating new rail lines and expanding existing ones, as rail continues to be a primary focus around the world of investment in the future of transportation.



selves to rail innovations. CAF has developed trains that include a number of technological advances. They can switch between Spain's wider track width and the usual European width; they're increasingly light, contributing to energy savings; and they operate with reduced vibrations and noise, reducing the impact on the people and ecosystems that the trains pass.

CAF's experience with trains of all kinds has translated into international success. CAF is supplying metro, tram, light rail, commuter, and regional trains to cities and countries that include Edinburgh, Stockholm, Belgrade, Turkey, Houston, and Sao Paulo. CAF has focused particularly on developing electric trains for tramways that can run without overhead power lines, or catenaries. Instead, they created an onboard energy-storage system, with high-speed recharging and a method for capturing the energy generated during the braking process.

CAF's new high-speed train, called Oaris, was designed collaboratively by CAF's research center and Spanish universities and technology centers, who labored to create an advanced train body that is fast, light, energy efficient, comfortable, and customizable for client needs. It is fully interoperable across borders, bridging differences of voltage, signaling systems, and track gauges.

President Obama's 2011 State of the Union speech depicted a vision where 80 percent of Americans would have access to high-speed rail within 25 years; and his 2012 budget includes \$8 billion for high-speed rail. Soon after President Obama's address, Vice President Biden announced a \$53 billion six-year project to continue construction of high speed and intercity passenger rail.

The railway vehicle manufacturer Talgo, capitalizing on more than 70 years of experience in the rail sector, has supplied high-speed trains to Oregon and Wisconsin. These can operate on existing rail lines at a significant improvement in speed. As Talgo's market development director Mario Oriol explains, the company sees this as a way to reinforce Talgo's presence in the United States market and prepare for improvements in rail that could lead to high-speed lines.

"These trains use advanced technology with lightweight construction, independent wheels, and an independent tilting system—which means that the trains adapt well to existing infrastructure," says Oriol. "If you can use such a train to improve travel time by 20 percent, this can give planners the justification to invest in future infrastructure." In addition to supplying trains throughout the Spanish high-speed system, Talgo is also currently providing tilting passenger coaches to the governments of Bosnia-Herzegovina and Kazakhstan and high-speed trains to the Republic of Uzbekistan.

Talgo's trains leverage advances in materials and engineering, which make the trains lighter and more energy efficient, more stable, and more comfortable. These advances will continue in the new Avril train, currently under development. Avril will be comfortable and energy efficient and will run at some of the highest speeds possible, and its wider body will accommodate an additional seat in each row. "It's a natural evolution based on



Talgo's new train Avril will be comfortable and energy efficient and will run at some of the highest speeds possible. It's the latest evolution of Talgo's extensive experience in designing and building high-speed trains.

Talgo's high-speed technology," points out Oriol, adding that the company will build mock-ups and should have a prototype by about 2013.

"High-speed has become fashionable in [the] U.S. Many projects and studies have been carried out in order to develop rail in several corridors," says Barron. High-speed rail has grown in Japan and in Korea and has exploded in China, he continues.

Poland is developing a new high-speed railway connecting four major cities. The Spanish engineering company Idom is part of a joint venture to analyze a potential layout for the railway, develop a proposal for the system, and plan its construction.

LINES UNDER CONTROL

Controlling a complex and rapidly changing transportation network demands total integration, which a program called DaVinci, designed by the information company Indra, supplies for Spain's network. DaVinci incorporates data that includes trains, signaling, energy inputs, timetables, and so on, and, with added algorithms to predict future delays or changes to the trains, allows the control room to easily manage the entire system in real time.

Indra first took its control experience overseas to the metro of Medellín, Colombia. The metro had been in operation for 15 years, running off what at the time was advanced metro technology. But the existing system was expensive to maintain, could not be scaled up to meet the needs of a growing



PHOTO COURTESY OF TALGO

city, and was 100 percent manually operated.

“One of the great advantages of DaVinci is that it can meet all those needs,” says Antonio García, Indra’s business development manager. “It can use any physical technology, or any information technology—IBM, HP, Oracle, whichever—that’s available in the market.”

Indra worked with the Colombian metro authority to design a system that would integrate all existing information available for the Medellín metro (including traffic, communication, energy, and related systems), and process it to allow for more automated control. This allowed Medellín to add trains to existing lines and build additional stops, all at a significantly reduced cost. Indra is now working with London’s transportation system to expand and improve the management of its infrastructure as well.

Indra is also bringing DaVinci to Lithuania. The government of Lithuania wanted to upgrade its system and expand the number of trains running along its routes. They too turned to Indra because the DaVinci system can integrate the information from the existing technology and process it automatically, without the need to buy additional hardware.

“From now on, they will be able to grow as much as they need to grow, wherever they want, and they can choose whichever technology they’d like,” says Desirée Meza, a senior engineer in Indra’s railway infrastructures division. “They will not need to change an entire system” to achieve significant improvements.

MADRID’S INNOVATIONS

In 1919, at the opening of Madrid’s new subway system, the entire track covered only two miles. Less than a hundred years later, the tracks have expanded to more than 175 miles in total, covering 12 nearby towns. These advances have garnered the Madrid Metro Authority a number of awards, including one for innovative use of technology awarded in 2009 at the international Metro Rail Forum.

Madrid Metro underwent a complete overhaul, implementing the most advanced technology, such as automated trains, and more than doubling the length of its tracks. After two major periods of renovation and expansion, more than 75 percent of citizens in the region live within easy access of a station, and half of all trips in the city are taken on public transportation.

Madrid Metro developed its own in-house research program, and it cooperates with Spanish and Latin American universities and companies to create technologies both for its own system and for export to other metros. They worked with the Polytechnic University of Madrid and Indra to create a new driver-training simulator that significantly cuts down on track-based driving practice while ensuring that new drivers achieve equal or greater competency. Madrid Metro has also developed advanced fixed overhead electric lines that allow trains to increase their maximum speed by 25 percent.

These new power lines have also been implemented in the Dominican Republic, on Santo Domingo’s new metro line, for which Madrid Metro was a primary consultant. Madrid Metro has taken its expertise to a number of other cities around the world; in addition to Santo Domingo, the authority has consulted or provided services to cities that include Buenos Aires, London, Quito, and Tunis.

After the bombing at its Atocha station in 2004, Madrid’s local transportation authorities invested heavily in state-of-the-art security and surveillance systems for its updated metro systems. As a result, says director Aurelio Rojo, the Madrid Metro network has 100 percent video surveillance coverage, and the system includes the most advanced security technologies in the world.

The engineering company Sener, which partially oversaw project development and management for both the Madrid and Barcelona metros, has also expanded throughout Europe, works in Qatar and in Mexico, and is now participating in a study for the new subway system of Bogotá, Colombia.

AN AUTOMATED RIDE

In the first car of Barcelona’s new driverless subway lines, passengers perch by the window and watch as the train rushes along the tracks and dips into tunnels. Far from inspiring fear of a lack of safety (a common concern for planners of driver-free lines), the conductor-free trains have become something of a tourist attraction.

Barcelona’s system attracted more than 1,200,000 riders a day in 2010, for a total of more than 381 million passengers over the year. Its five percent growth over 2009 was sparked

by both improvements to existing lines and the implementation of new ones—in particular three automated lines put in place during 2009 and 2010. (Two lines were entirely new; the third was an existing line that was transformed into an automatic one.)

Barcelona Metro has hosted about 800 visits from governments of different cities and countries. The municipality has taken its experience overseas: the authority is serving as an advisor to the government of Panama, which is designing that country's first subway line, and to the mass transit administrations in Santiago de Chile, Buenos Aires, Bogotá, and other South American cities.

Madrid Metro, which more than doubled its track mileage and capacity in recent years, also implemented a new automatic system on three of its lines, and today serves about 2.5 million passengers a day. The implementation of these advances allowed Madrid to significantly and safely increase the number of trains on each track, with less wait time between trains.

Automatic train-operating systems are attractive to transportation planners for a number of reasons: they demand fewer staff resources, they're safer than traditional trains, and the trains can run more frequently, with greater accuracy and less wear on the equipment. Creating lines with the new signaling system has also allowed the transportation authority to keep lines running for extended hours during special events or festivals, without a significant increase in cost.

"Currently in the mass transit market, we are facing a high demand for an increase in capacity," explains Beatriz Muñoz, product line manager for the rail control and signaling company Dimetronic, involved in the development of the Barcelona and Madrid lines.

In the past, driverless trains operated on tracks equipped with detectors to determine whether a train was on top of that particular segment. The latest system that Dimetronic and other companies have developed is called communication-based train control (CBTC) and involves constant radio communication between the track and the train. With this system, the control center is aware at all times of the exact location of every train, and can communicate directly with the train in real time to avoid dangerous situations. This technology also involves energy-saving algorithms, such as one that detects a downhill gradient and instructs a train not to accelerate, since the downhill slope will accelerate the train without any increase in power. CBTC-controlled trains can increase the capacity of a given line up to about 30 percent more passengers per day.

The first line in Madrid to be controlled by CBTC technology began running in October 2010. Dimetronic is also involved in creating a new line powered by CBTC in Sao Paulo, Brazil, which is slated to open by the end of 2011; another in Caracas, Venezuela; and a totally unmanned line in Singapore.

Not long ago, Sener was asked to evaluate the problems that were plaguing an overcrowded subway line in Santiago

de Chile, in Chile. The government found itself having to temporarily close down stations, because there was simply no more room for passengers. One long-term solution may be to build a parallel line, but in the short term, Sener engineers have found that more trains can be added by introducing a driverless system and automating the line. This has increased the line's capacity without the need for expensive new construction.

POWERING THE SYSTEM

A major concern for local transportation authorities and companies involved in rail is how to cut down on energy use, and how to recover available energy. Ingeteam, an electrical engineering company, has a division devoted to rail, from light rail and subways to high-speed trains. The company can supply a train's entire power system, including the motor, its controls, power electronics, and onboard electrical solutions.

The company's latest innovation offers a novel method to capture the energy expended by braking at the station. "Usually, that energy can be captured by the electrical lines and fed into another train that needs energy," says Angel Laurrieta, CEO of Ingeteam's traction division. "But that situation doesn't always occur, because there isn't always a match between a braking and accelerating train."

So to avoid wasting braking energy—of particular interest to city-based metros and regional trains—Ingeteam engineers designed a system that directs the energy straight into the rail's electrical system and allows it to be used by any other part of the same system. "This can supply about 10 percent of the total energy needs for the train," says Laurrieta. The system works in parallel with any existing physical setup, extracting the energy and routing it to other uses within the network.

"This is incredibly important," points out Laurrieta. "Rail administrations are quite conservative," and are interested in new technologies that obviate the need to change existing hardware.

The system has thus far been in operation for a year in the metro system of Bilbao, in the north of Spain. Ingeteam has attracted interest from public transportation systems in the U.S. and in other cities in Europe and Latin America.

Spain's rail expansion continues to attract visitors from around the world. Jiménez highlights ADIF's collaboration with countries like Russia, Turkey, and Poland as they develop high-speed lines, noting that ADIF has also played an advisory role to the state of California's rail planning efforts. Clausecker adds that UNIFE regularly brings representatives from Eastern European countries, such as Poland, Romania, and the Czech Republic, to Spain to learn from the Spanish system. As Clausecker concludes, "Spain is a role model for infrastructure investments."

Learn more at www.technologyreview.com/spain/hsrail

A Motorola Atrix 4G smartphone is docked into a black plastic Lapdock. The Lapdock's screen is tilted back at an angle, displaying a Firefox browser interface with various web pages and images. The smartphone's screen is also visible, showing a standard Android interface. The background is a gradient of yellow and orange, with a red rectangular area in the top right corner containing the text 'to market'.

to market

COMPUTING

Super Phone

SOME OTHER smart phones can be connected to a keyboard, but this Android-based dual-core phone can also be connected to a dock with an 11.6-inch screen. Blurring the lines between a smart phone and a netbook, the Atrix 4G comes with a number of applications specifically designed for this larger canvas: the battery-powered dock lets users surf using a full-featured Firefox browser, watch videos, and edit documents.

■ **Product:** Atrix 4G with Lapdock **Cost:** \$600 **Availability:** Now
Source: www.motorola.com **Company:** Motorola



BIOMEDICINE

Mobile Diagnostics

RADIOLOGISTS and oncologists can use this app to read CT, MRI, and PET scans on an iPhone or iPad. A built-in test asking users to distinguish between slightly different shades on the screen ensures that lighting conditions are suitable for discerning subtle detail. Doctors can zoom, annotate images, use false colors to enhance detail, and measure precise distances between features that appear in the scan.

■ **Product:** MobileMIM **Cost:** Free **Availability:** Now **Source:** www.mimsoftware.com **Company:** MIM Software



BIOMEDICINE

Artificial Vision

PEOPLE BLINDED by degenerative eye disease could have some of their sight restored by the first commercial retinal prosthesis. A camera mounted on a pair of glasses feeds an image to an array of 60 electrodes implanted in the wearer's retina. Although the resulting vision is limited, it's good enough for recognizing simple objects, finding doors and windows, and, in some cases, even reading large print.

■ **Product:** Argus II **Cost:** \$115,000 **Availability:** Now **Source:** www.2-sight.eu **Company:** Second Sight

COURTESY OF MIM SOFTWARE (DIAGNOSTICS); SECOND SIGHT MEDICAL PRODUCTS (VISION)

Name

Dr. Dennis Hong

Job Title

*Associate Professor of
Mechanical Engineering,
Virginia Tech*

Area of Expertise

Robotics

LabVIEW Helped Me

*Convey and respond to
vast amounts of data in
real time*

Latest Project

*Design and prototype a
car that can be driven by
the blind in just 4 months*

NI LabVIEW

LabVIEW makes me better because

CODE REUSE

saves time and effort

>> Find out how LabVIEW can make you better at ni.com/labview/better

800 453 6202



COMPUTING

Active Listening

TWO ONBOARD microprocessors power this Bluetooth wireless headset. Users can download apps for tasks such as writing and sending e-mail with a speech-to-text system. An accelerometer allows functions to be controlled by tapping or shaking the headset. For instance, a vigorous shake will put the headset into pairing mode, where it can be linked to the user's phone.

■ **Product:** Jawbone Era
Cost: \$130 **Availability:** Now **Source:** www.jawbone.com **Company:** Jawbone



ENERGY

Water Power

THIS MOBILE USB charger uses a fuel-cell cartridge. Inside the cartridge is a coiled flexible foil strip, about as thick as a Band-Aid, that contains the exchange membrane and fuel. The cell is activated when the user fills a small built-in tank with water. Unlike other fuel cells, it requires no pumps, increasing efficiency and reducing weight.

■ **Product:** PowerTrek **Cost:** About \$200 **Availability:** Fall 2011 **Source:** www.powertrekk.com **Company:** myFC



COMPUTING

Faster Interfaces

APPLE'S NEW LAPTOPS are the first computers to use Intel's Thunderbolt interface technology, which is intended to replace Firewire and USB and eliminate the need for a separate port to connect displays. Up to six devices can be daisy-chained to a single Thunderbolt port (identified by a lightning-bolt symbol), with transfer speeds of up to 10 gigabits per second—twice that of USB 3.0 and 20 times that of USB 2.0. The interface works by providing external access to the high-speed bus used inside PCs to connect expansion cards.

■ **Product:** 15-inch MacBook Pro **Cost:** \$1,800 **Availability:** Now **Source:** www.apple.com **Companies:** Apple, Intel

CHRISTOPHER HARTING (LISTENING, WATER); COURTESY OF APPLE (INTERFACE)

Name

Dr. Laurel Watts

Job Title

*Principal Software
Engineer*

Area of Expertise

Chemical Engineering

LabVIEW Helped Me

*Control multiple
instruments operating in
harsh conditions*

Latest Project

*Engineer the ultimate
storm chaser*

NI LabVIEW

LabVIEW makes me better because the

INTEGRATION

with hardware is so seamless

>> Find out how LabVIEW can make you better at ni.com/labview/better

800 453 6202





COMPUTING

Play Phone

IN RESPONSE to the runaway success of smart phones as a platform for casual games, Sony Ericsson has created a phone designed for game enthusiasts. Instead of a slide-out QWERTY keyboard, it features a slide-out game pad and a processor that can deliver 3-D graphics at 60 frames per second.

■ **Product:** Xperia Play
Cost: Not available
Availability: Spring 2011
Source: www.sonyericsson.com
Company: Sony Ericsson

BIOMEDICINE

Selective Hearing

ORIGINALLY DEVELOPED for soldiers, these earplugs can muffle loud noises while admitting or amplifying soft ones. This allows soldiers (or hunters or construction workers) to listen to conversations and other important sounds around them while protecting their hearing from the din of machinery or deafening blasts.

■ **Product:** EB15
Cost: \$500
Availability: Now
Source: www.etymotic.com
Company: Etymotic Research



COURTESY OF SONY ERICSSON (PHONE); CHRISTOPHER HARTING (HEARING)

Name

Peter Simonsen

Job Title

*Design Engineer,
Embedded Software*

Area of Expertise

Renewable Energy

LabVIEW Helped Me

*Perform real-world
simulations with total
control of the application*

Latest Project

*Develop a test architecture
for verification of wind
turbine control systems*

NI LabVIEW

LabVIEW makes me better because I can

SIMULATE

real-world systems

>> Find out how LabVIEW can make you better at ni.com/labview/better

800 453 6202



ENERGY

Challenging Hybrids

THE ALL-GASOLINE-powered Chevy Cruze Eco is competing with hybrids on fuel efficiency, thanks to a light, turbo-charged internal-combustion engine. With the help of improved vehicle aerodynamics (including a set of lower-front-grille shutters that automatically close to reduce drag at highway speeds), this engine delivers highway gas mileage of 42 miles per gallon—making the car more fuel-efficient than any current-model hybrid tested by the U.S. Environmental Protection Agency, save the Toyota Prius.

■ **Product:** Cruze Eco
Cost: \$19,000 **Availability:** Now
Source: www.chevrolet.com
Company: Chevrolet



BIOMEDICINE

Stress Detector

THIS WRISTBAND measures galvanic skin response throughout the day to gauge emotional arousal, indicating when the wearer is excited or stressed. Information is downloaded from the bracelet for later analysis on a computer. The system can be used to monitor patients, aid market research and product testing, or help people learn to manage stress.

■ **Product:** Q-Sensor **Cost:** \$2,000 **Availability:** Now **Source:** www.affectiva.com **Company:** Affectiva

COMPUTING

Wireless Weigh-In

THIS WI-FI-ENABLED scale can post the user's weight, fat mass, and body mass index on Twitter or Facebook. For the more discreet, results can instead be sent to a smart-phone app that charts the data over time.

■ **Product:** Withings Body Scale **Cost:** \$160 **Availability:** Now
Source: www.withings.com **Company:** Withings



COURTESY OF CHEVROLET (CAR); CHRISTOPHER HARTING (STRESS); COURTESY OF WITHINGS (WEIGHT)

MOBILEAPPS

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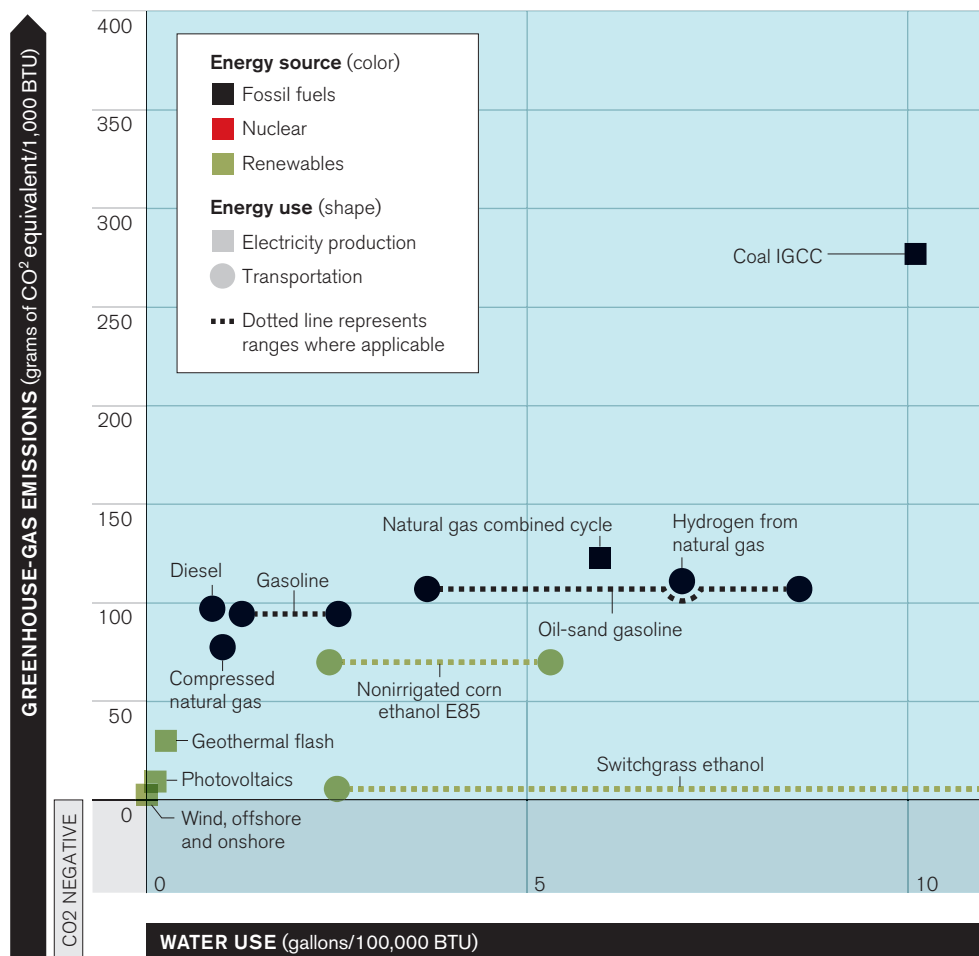


Water Power

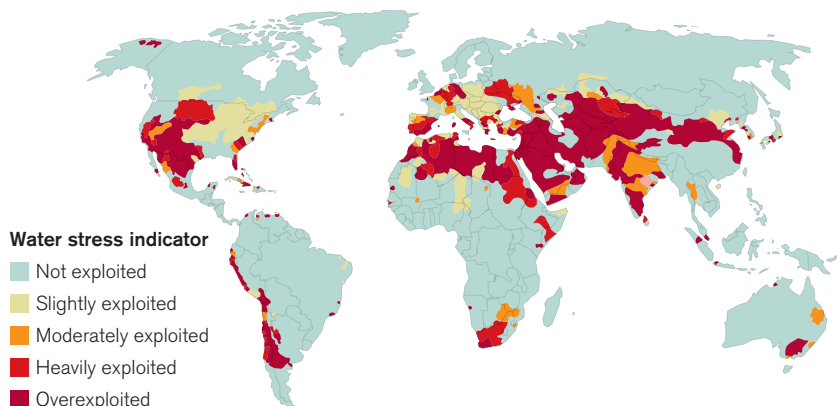
Decisions about future energy sources will need to factor in water consumption as well as greenhouse-gas emissions.

In the United States, energy production will account for almost 90 percent of the projected increase in consumption of freshwater between 2005 and 2030, according to Argonne National Laboratory. Power plants that use nuclear fission or fossil fuels, such as coal and natural gas, consume billions of gallons of water per day for cooling. Fossil-fuel plants that use carbon-capture technologies to cut carbon dioxide emissions consume even more water than conventional ones. As for renewable energy sources, they present a mixed water-use picture. While wind power and photovoltaic solar power use little water, solar thermal power—one of the fastest-growing renewable sectors—uses a great deal. Biofuels from non-irrigated sources, such as switchgrass, use relatively little water, but ethanol made from irrigated corn is hugely water-intensive. In the chart at right, we compare recent estimates of average lifetime water consumption and greenhouse-gas emissions for various electricity sources and transportation fuels. Note the water-use range of irrigated corn ethanol. The water consumption associated with E85, a blend of 85 percent ethanol and 15 percent gasoline, ranges from 20 to nearly 1,000 gallons per 100,000 BTU, depending on agricultural practices. —Mike Orcutt

GREENHOUSE-GAS EMISSIONS AND WATER USAGE FOR VARIOUS SOURCES OF FUEL AND ELECTRICITY



WATER SCARCITY MAP



Source: Smakhtin, Revenga and Döll, 2004

Information graphic by
TOMMY McCALL and
MIKE ORCUTT

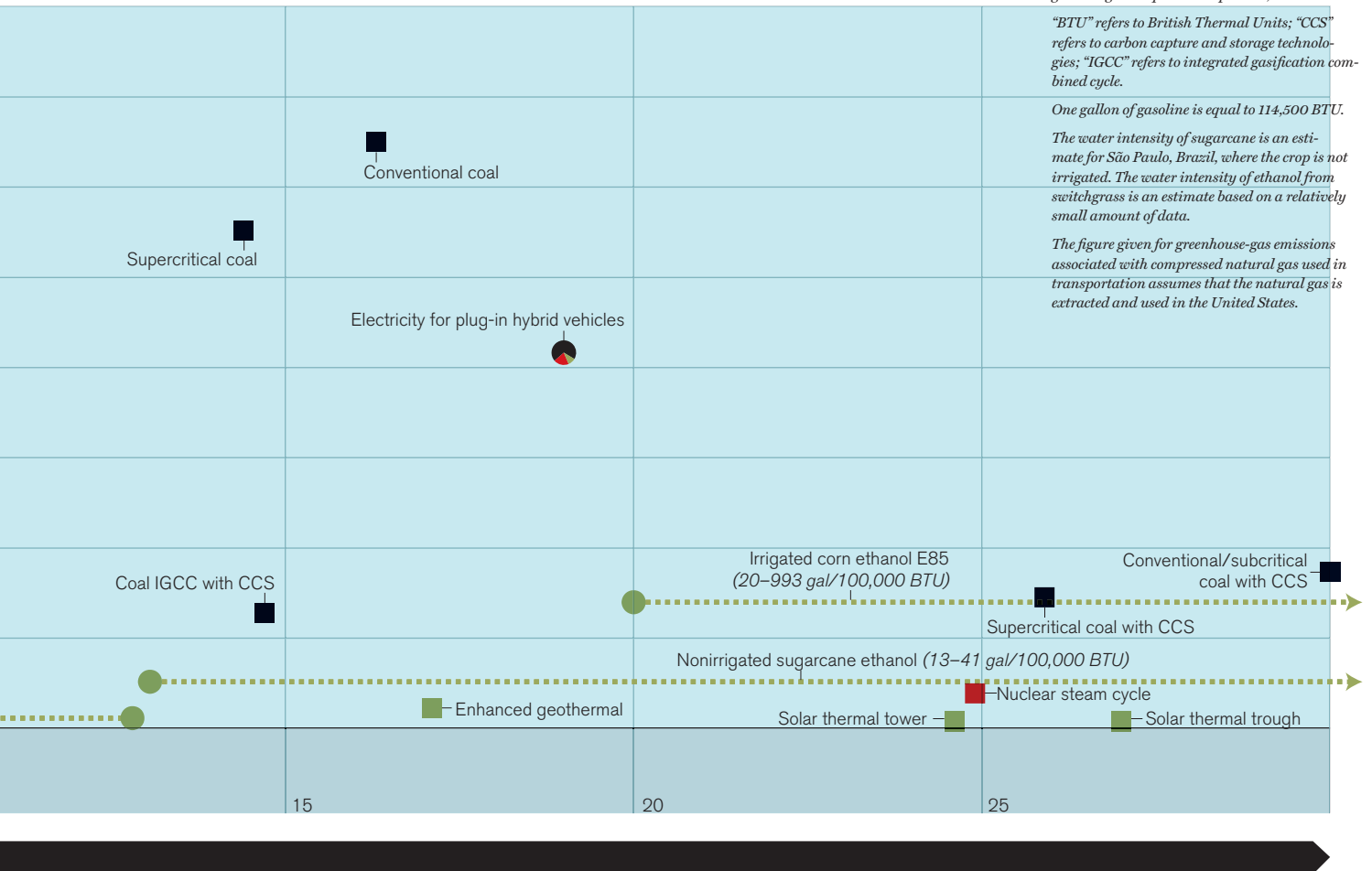
Sources: Energy Policy; Environmental Science & Technology; Argonne National Lab; Congressional Research Service; National Energy Technology Laboratory; Carey King

"Geothermal" refers to flash-steam-powered plants and is given in grams of carbon dioxide (gCO₂) per 100,000 BTU. All other figures are given in gCO₂ equivalents per 100,000 BTU.

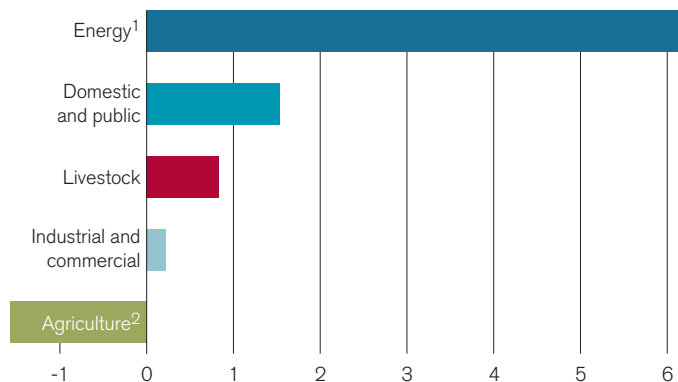
"BTU" refers to British Thermal Units; "CCS" refers to carbon capture and storage technologies; "IGCC" refers to integrated gasification combined cycle.

One gallon of gasoline is equal to 114,500 BTU.
The water intensity of sugarcane is an estimate for São Paulo, Brazil, where the crop is not irrigated. The water intensity of ethanol from switchgrass is an estimate based on a relatively small amount of data.

The figure given for greenhouse-gas emissions associated with compressed natural gas used in transportation assumes that the natural gas is extracted and used in the United States.

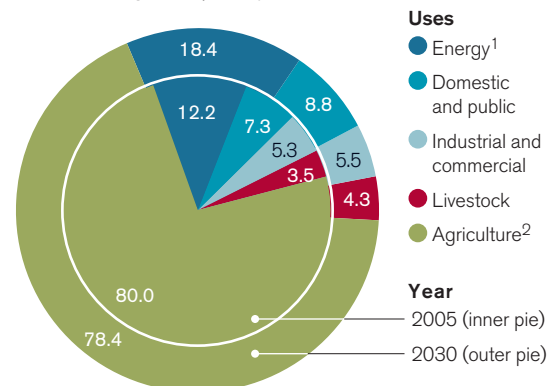


CHANGE IN U.S. WATER CONSUMPTION FROM 2005 TO 2008
(in billions of gallons per day)



Notes: ¹Includes bioenergy ²Other than bioenergy

U.S. WATER CONSUMPTION
(in billions of gallons per day)



Notes: ¹Includes bioenergy ²Other than bioenergy

Q&A

Una Ryan

A biotech executive explains her innovative business model for funding diagnostic tests in poor countries.

As the head of Diagnostics for All, a nonprofit founded in 2007, Una Ryan has one goal: to change the way health care is delivered in poor countries. The organization is developing paper diagnostics—cheap, portable, easy-to-manufacture tests that can be used in environments with few resources and little infrastructure (see “*TR10: Paper Diagnostics*,” *March/April 2009*).

The key to the nonprofit's success is an innovative business model. Diagnostics for All has won grants and philanthropic funding to support early development of its technology. But Ryan knows that these types of funds are inadequate for deploying new medical tests over the long term. So Diagnostics for All has created a for-profit subsidiary, Paper Diagnostics, which will partner with companies to develop tests for use in wealthy nations. After taxes, the proceeds will be invested back into the nonprofit.

The organization's most advanced test, for liver function, is designed to help people who take HIV and tuberculosis medications that can cause liver damage. A doctor can use the test to quickly determine when a patient's drug or dosage should be changed. Emily Singer, *TR*'s senior editor for biomedicine, asked Ryan how she expects to deploy this technology in poor countries.

TR: What makes Diagnostics for All's business model unique?

Ryan: We have created a nonprofit and a wholly owned for-profit. That will allow us to take the technology and work with partners who want to make money. But we will get royalties and put them back into a fund to allow Diagnostics for All to do more tests and develop more products. I am trying to build sustainability in terms of delivery to people in the developing world, but also for DFA. I want it to be here long after I am gone.

How will you work with companies? Will you license the technology or work with them to develop products?

We can envisage different models being suitable for different relationships, including straight licensing deals, joint ventures, and shared development. We have several ongoing corporate relationships but have not announced anything publicly.

What kinds of diagnostic tests are you developing?

In addition to the liver function test, we already have a pregnancy test and a glucose test [for diabetes monitoring]. But one of the biggest advantages of the technology is that the applications are broad. We can test food products. We can put the technology into thread to look for infections in wounds, we can put it in diapers. The cost of the test is not limiting—it's all about what you do with the test. This is a very good way of accurate intelligence gathering on health and disease.

You previously headed a public company. Why did you decide to take on the job at Diagnostics for All?

DFA represents an opportunity to fundamentally change the way we look at health care worldwide. If one can make a device that meets the qualifications for success in the developing world—one that can be produced at low prices on a massive scale, that is easy to use, portable, and disposable—it will likely be a dynamite product for the developed world as well.

Many attempts to bring technology to poor countries have failed. Health clinics are littered with broken centrifuges and other instruments. How do you plan to avoid these problems?

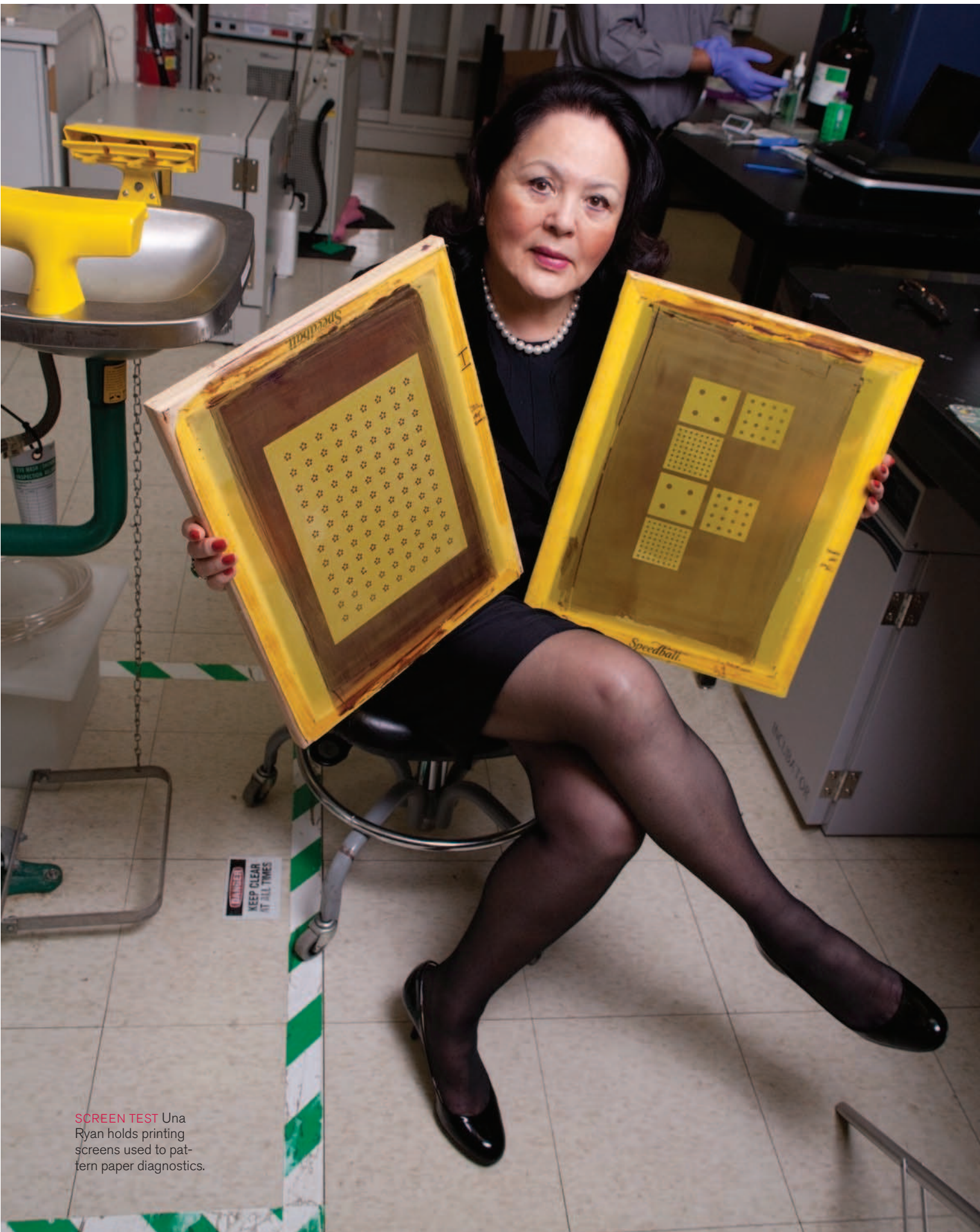
You have to have the right technology, one that is intrinsically low cost. The second thing you have to have is the right business model. You can get a lot of stuff worked on or researched—students will work on a project for one summer, or people will make donations during the holiday season—but to get to the end user, we need something scalable and sustainable. I have done many experiments with dual markets [which sell one product to poor countries and a related product to wealthy ones] and tiered pricing [with different prices for different markets], but I think this is a winner.

What have been the biggest hurdles in achieving your vision for Diagnostics for All?

Initially, it's getting unrestricted funding. A lot of grant funding often excludes legal expenses, consultants, or overhead for paying employees. The other hurdle is always the regulatory one. Satisfying regulatory bodies all over the world is expensive. We have made something that is almost zero cost to make—a 300th of a cent to print them. But by the time it goes through the regulatory process, we have to add a few cents.

How will you deliver the technology?

Initially, we will work with hospitals and clinics where there is already some infrastructure, because we don't have feet on the ground all over the world. One thing we can do is deliver them at scale. And they are portable enough to be delivered by someone on a bicycle. We also want to go more nontraditional routes, such as small NGOs and e-health clinics. I would like to see these paper diagnostics available at a convenience store, just like chewing gum. In South America, we might work with generic pharmacies, which tend to be next to doctors' offices. **tr**



SCREEN TEST Una Ryan holds printing screens used to pattern paper diagnostics.


PHOTO ESSAY

Rocket Road

When NASA stops flying the space shuttles later this year, the United States will no longer have a vehicle to carry humans to space—unless commercial industry can fill the gap. Last year, Space Exploration Technologies (SpaceX) became the first company to send a spacecraft into low Earth orbit and have it reënter the atmosphere. The flight is part of a partnership with NASA, which has awarded SpaceX \$1.6 billion for at least 12 flights to carry cargo to the International Space Station. But SpaceX's goal is something far greater: a NASA contract to carry humans to space.

By BRITTANY SAUSER





Preparing for its first test flight, the Falcon 9 rocket sits at SpaceX's launch site in Cape Canaveral, Florida (far left). Approximately 55 meters tall and four meters wide, the two-stage rocket is powered by nine hydrocarbon Merlin engines. It is made of an aluminum-lithium alloy and a carbon fiber-aluminum composite. Here, a carbon-composite interstage of the rocket is shown undergoing final assembly in California. The four black containers hold parachutes used to return the first stage of the rocket to Earth after separation from the second stage, which carries the vehicle to its targeted orbit.



SpaceX carries out more than 80 percent of its spacecraft design and manufacturing in a 550,000-square-foot facility (above) located on Rocket Road in Hawthorne, California. The company, which was founded in 2002, moved into the building in 2008. Here, engineers work on the avionics and control systems for the Falcon 9 rocket.

The Merlin engine (right) operates on a gas-generator power cycle, using kerosene and liquid oxygen as propellants. Its injector design was first used in an Apollo spacecraft and has a long history of reliable spaceflight. The engine's combustion chamber and nozzles are regeneratively cooled to increase thrust without increasing mass.

MISHA GRAVENOR

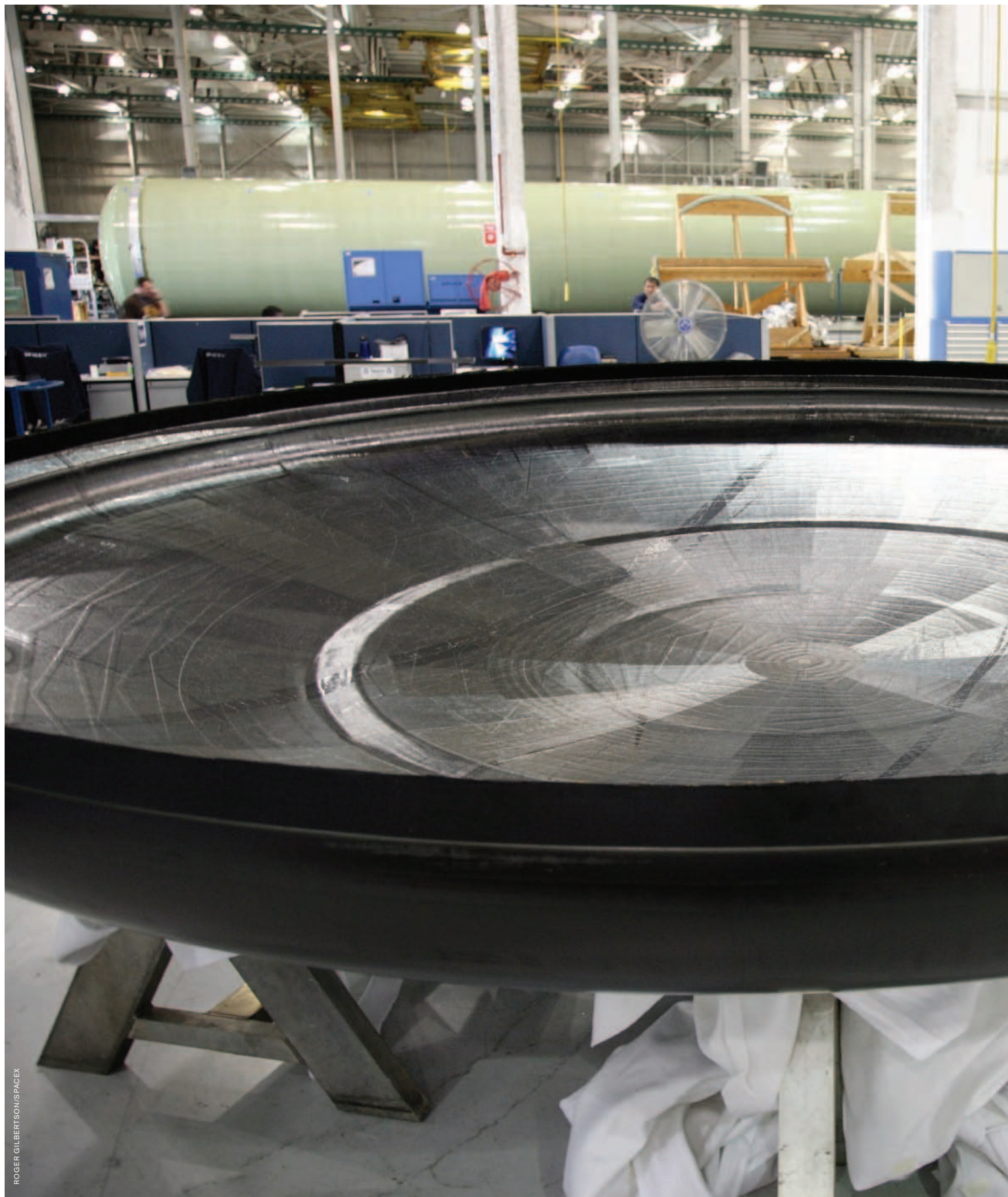






SpaceX's capsule for carrying cargo and crew to space is named Dragon. It will use as many as 18 thrusters for orbital maneuvering and attitude control. The thrusters are mounted on the spacecraft in groups of four and five. At left, an engineer inspects the thrusters, which were fabricated in a clean room, before they are sent to SpaceX's testing facility in Texas.

The California facility houses an engineering model of the Dragon (above left). The reusable capsule can transport payloads of up to 6,000 kilograms and seven crew members to low Earth orbit. To carry humans, it will include life-support and launch-abort systems. SpaceX's second Dragon test capsule (right, under construction) is scheduled to fly later this year.



ROGER GILBERTSON/SPACEX



The Dragon capsule's heat shield is intended to protect the spacecraft during reentry into Earth's atmosphere. At nearly four meters in diameter, it is the largest such shield to be used on a spacecraft. It has a carbon-composite structure, shown here, that supports heat-shield tiles. SpaceX worked closely with NASA to develop the tile technology. Each tile weighs about a kilogram and can withstand temperatures up to 2,000 °C.

S POTLIGHT ON INNOVATION

A TECHNOLOGY REVIEW CUSTOM SERIES

STORAGE: THE KEY TO CLEAN ENERGY'S FUTURE

As the energy and transportation sectors of the United States economy begin to show signs of renewal and transformation, how to store energy better remains an important national issue. U.S. Department of Energy Secretary Steven Chu, testifying before the Senate in early 2010, focused on the need to create storage that can support an advanced energy grid, renewable power, and electric vehicles.

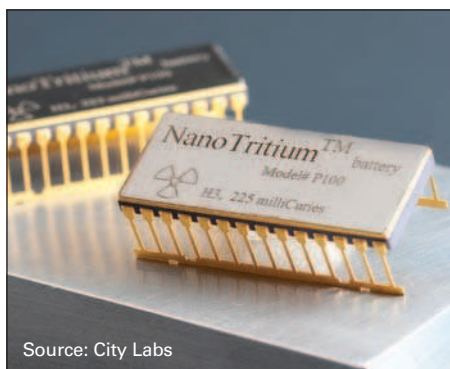
ARPA-E, the DOE's advanced research project for energy, is devoting more than \$400 million in grants to the development of energy technologies, including the batteries needed for storage of electrical energy. In March 2011, U.S. Navy Secretary Ray Mabus announced a research partnership with ARPA-E. "One of the things that holds us back is our [in]ability to store energy," Mabus told the 2011 MIT Energy Conference in his keynote address.

Improvements in Solid-State Batteries

Lithium ion (li-ion) batteries are currently the technology of choice for today's hybrid and electrical vehicles. There are, however, a number of limitations to the technology, such as the length of the battery's life. Many battery experts believe that the batteries of the future will be solid state, but today's solid-state batteries are prohibitively expensive to manufacture.

"Using [existing manufacturing] processes could cost as much as a thousand times more" than the equivalent li-ion batteries, says entrepreneur Scott Faris, founder of Orlando, FL-based Planar Energy. "The process is slow, and it's historically only been used for very small surface areas."

Planar Energy recently won a \$4 million Department of Energy award under



Source: City Labs

ARPA-E to develop and manufacture the company's new solid-state batteries, which Faris says can be made for half the cost of the current li-ion technology and offer triple the performance.

Flat Power

On February 14, MasterCard and Symantec Corporation announced a new credit card for the U.S. market with advanced security features. Existing card security relies on short numeric codes, but those codes, like the card number itself, these can be easily stolen and used for internet purchases. The new cards feature a display that generates single-use passwords.

The card's new display and mini electronic system is supported by Lakeland, FL-based Solicore's paper-thin battery technology.

Solicore was founded in 2001, and its founders quickly noticed that the market needed new technology to power displays like those on credit cards. But no existing product was thin and flexible enough to be embedded in a card.

With the help of a team of battery experts, company researchers developed a lithium battery where the anode and cathode are separated by a (proprietary) thin layer. "It's coated on, and it looks as if it's solid, but it can bend and flex,"

says Dave Eagleson, vice president of sales. This technology was first used in credit cards in Europe and Asia. The new MasterCard is the first major card in the United States to offer single-use security coding powered by Solicore's thin, flexible battery.

Betavoltaic Batteries

Current chemical batteries have a number of limitations, including their short lifespan and the limited range of temperatures and pressures at which they can function. Peter Cabauya of City Labs Inc. in Homestead, FL, discovered these limitations when he and his cofounders looked into starting a new technology company in south Florida.

Founded in 2005 and first housed within Florida International University's technology incubator, City Labs originally partnered with Lockheed Martin Florida to develop betavoltaic batteries. Like photovoltaic cells, betavoltaic batteries absorb radiation, but instead of sunlight, the radiation comes from a physical source that emits electrons.

City Labs focused on tritium as a radiation source, as tritium—one of the most benign radioisotopes—is already used to power the phosphorescent glow in the watches used by divers and in exit signs (the signs are not battery powered). In December 2010, the company was awarded a contract worth nearly \$1 million from the U.S. Air Force Research Laboratory for its tritium-based batteries.

Download the *Storage* white paper to learn more about

- battery-powered bandages;
- CPR advances through batteries; and
- a new generation of fuel cells

Download the full story and more at www.technologyreview.com/spotlight





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Every year, *Technology Review* looks at the advances that have happened over the previous year and chooses 10 emerging technologies that we think will have the greatest impact. The ultimate criterion is straightforward: is the technology likely to change the world? This year's group includes high-energy batteries that could make cheaper hybrid and electric vehicles possible and a new class of electrical transformers that could stabilize power grids. Some of our choices will alter how you use technology: you'll be tapping into computationally intensive applications on mobile devices, or using gestures to command computers that are embedded in televisions and cars. Other choices could improve your health; for instance, doctors will craft more effective cancer treatments by understanding the genetics of individual tumors. But no matter the category, all 10 promise to make our lives better. —*The Editors*

Facebook remaps the Web to personalize online services

Social Indexing

Bret Taylor wants to make online services more attuned to what you really want. Search sites could take your friends' opinions into account when you look for restaurants. Newspaper sites could use their knowledge of what's previously captured your attention online to display articles you are interested in. "Fundamentally, the Web would be better if it were more oriented around people," says Taylor, who is Facebook's chief technology officer. To bring this idea to fruition, he is creating a kind of social index of the most frequently visited chunks of the Web.

Many sites have tried to personalize what they offer by remembering your past behavior and showing information they presume will be relevant to you. But the social index could be much more powerful because it also mines your friends' interests and collects information from multiple sites. As a result, the index can give websites a sense of what is likely to interest you even if you've never been there before.

This ambitious project gets much of its information from the simple "Like" button, a thumbs-up logo that adorns many Web pages and invites visitors to signal their appreciation for something—a news story, a recipe, a photo—with a click. Taylor created the concept in 2007 at FriendFeed, a social network that he cofounded, which was acquired by Facebook in 2009. Back then, the button was just a way to encourage people to express their interests, but in combination with Facebook's user base of nearly 600 million people, it is becoming a potent data-collecting tool. The code

behind the Like button is available to any site that wants to add it to its pages. If a user is logged in to Facebook and clicks the Like button anywhere on the Web, the link is shared with that person's Facebook friends. Simultaneously, that thumbs-up vote is fed into Taylor's Web-wide index.

That's how the *Wall Street Journal* highlights articles that a person's friends enjoyed on its site. This is what lets Microsoft's Bing search engine promote pages liked by a person's friends. And it's how Pandora creates playlists based on songs or bands a person has appreciated on other sites.

This method of figuring out connections between pieces of content is fundamentally different from the one that has ruled for a decade. Google mathematically indexes the Web by scanning the hyperlinks between pages. Pages with many links from other sites rise to the top of search results on the assumption that such pages must be relatively useful or interesting. The social index isn't going to be a complete replacement for Google, but for many types of activity—such as finding products, entertainment, or things to read—the new system's personal touch could make it more useful.

Google itself acknowledges this: it recently rolled out a near-clone of the Like button, which it calls "+1." It lets people signify for their friends which search results or Web pages they've found useful. Google is also using Twitter activity to augment its index. If you have connected your Twitter and Google accounts, Web links that your friends have shared on Twitter may come up higher in Google search results.

Another advantage of a social index is that it could be less vulnerable to manipulation: inflating Google rankings by creating extra links to a site is big business, but buying enough Facebook likes to make a difference is nearly impossible, says Chris Dixon, cofounder of Hunch, a Web startup that combines its own recommendation technology with tools from Facebook and Twitter. "Social activity provides a really authentic signal of what is authoritative and good," says Dixon. That's why Hunch and other services, including an entertainment recommendation site called GetGlue, are building their own social indexes, asking people to record their positive feelings about content from all over the Web. If you're browsing for something on Amazon, a box from GetGlue can pop up to tell you which of your friends have liked that item.

A social index will be of less use to people who don't have many online connections. And even Facebook's map covers just a small fraction of the Web for now. But about 10,000 additional websites connect themselves to Facebook every day. —Tom Simonite

BRET TAYLOR

(Facebook) Using social networks to filter information will make websites smarter.

OTHERS WORKING ON SOCIAL INDEXING

GetGlue, New York

Hunch, New York

Twitter, San Francisco

Google, Mountain View, California

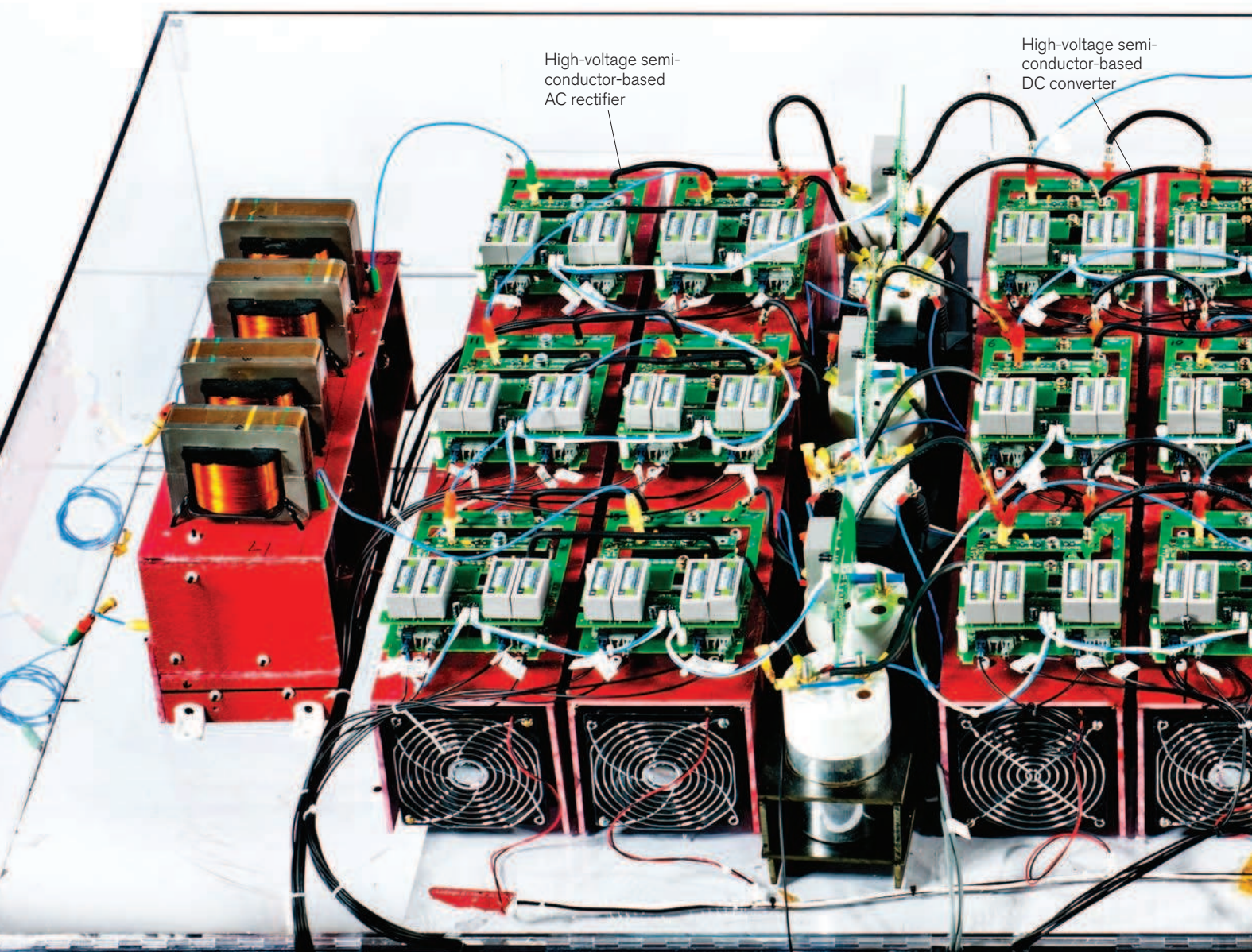
RESULTS YOU'LL LIKE
Bret Taylor created the concept of the "Like" button.



Controlling the flow of electricity to stabilize the grid

Smart Transformers

In a lab wired up to simulate a residential neighborhood, Alex Huang is working to revamp aging power grids into something more like the Internet—a network that might direct energy not just from centralized power stations to consumers but from any source to any destination, by whatever route makes the most sense. To that end, Huang, a professor of electrical



engineering at North Carolina State University, is reinventing the transformers that currently reduce the voltage of the electricity distributed to neighborhoods so that it's suitable for use in homes and offices.

His new transformer will make it easier for the grid to cope with things it was never designed for, like charging large numbers of electric vehicles and tapping surplus elec-

tricity from residential solar panels. Smart meters in homes and offices can help by providing fine-grained information about the flow of electricity, but precise control over that flow is needed too. Not only would this stabilize the grid, but it would better balance supply and demand, reducing spikes so that fewer power plants would be needed to guarantee the electricity supply.

“We need a radically new device to sit between homes and grid to provide a buffer, so that the grid will remain stable no matter what is going on in the homes,” Huang says. Conventional transformers handle only AC power and require manual adjustment or bulky electromechanical switches to redirect energy. What he wants is a compact transformer that can handle DC as well as

POWERFUL ELECTRONICS The smart transformer can handle both AC and DC power. Thanks to semiconductors capable of handling high voltages, it can be programmed to redirect the flow of electricity in response to fluctuations in supply and demand.

Control circuitry

High-frequency transformers

AC and can be electronically controlled so that it will respond almost instantaneously to fluctuations in supply and demand. If one neighbor plugged an electric car into an AC charger, for example, it could respond by tapping otherwise unneeded DC power from another neighbor's solar panels.

To build such a transformer, Huang started developing transistors and other semiconductor-based devices that can handle thousands of volts, founding the Future Renewable Electric Energy Delivery and Management Systems Center at NC State in 2008. His first transformer had silicon-based components, but silicon is too unreliable for large-scale use at high voltages. So Huang has pioneered the development of transformers with semiconductors based on compounds of silicon and carbon or gallium and nitrogen, which are more reliable in high-power applications. He expects to have a test version of the silicon-carbon transformer ready in two years and to have a device that utilities can test in five years.

Huang's transformers would make connecting a solar panel or electric car to the grid as simple as connecting a digital camera or printer to a computer. That would reduce our reliance on fossil fuels by making it easier for small-scale sources of cleaner energy to contribute to the grid. He says, "The real benefit to society will come when there's an aggregate effect from many, many small generators, which we hope will be renewable and sustainable energy sources."

—David H. Freedman

ALEX HUANG

(North Carolina State University)
Directing the flow of energy more precisely could mean more resilient and efficient grids.

OTHERS WORKING ON SMART TRANSFORMERS

Amantys, Cambridge, U.K.
Cree, Durham, North Carolina
Electric Power Research Institute, Palo Alto, California

Controlling computers with our bodies

Gestural Interfaces

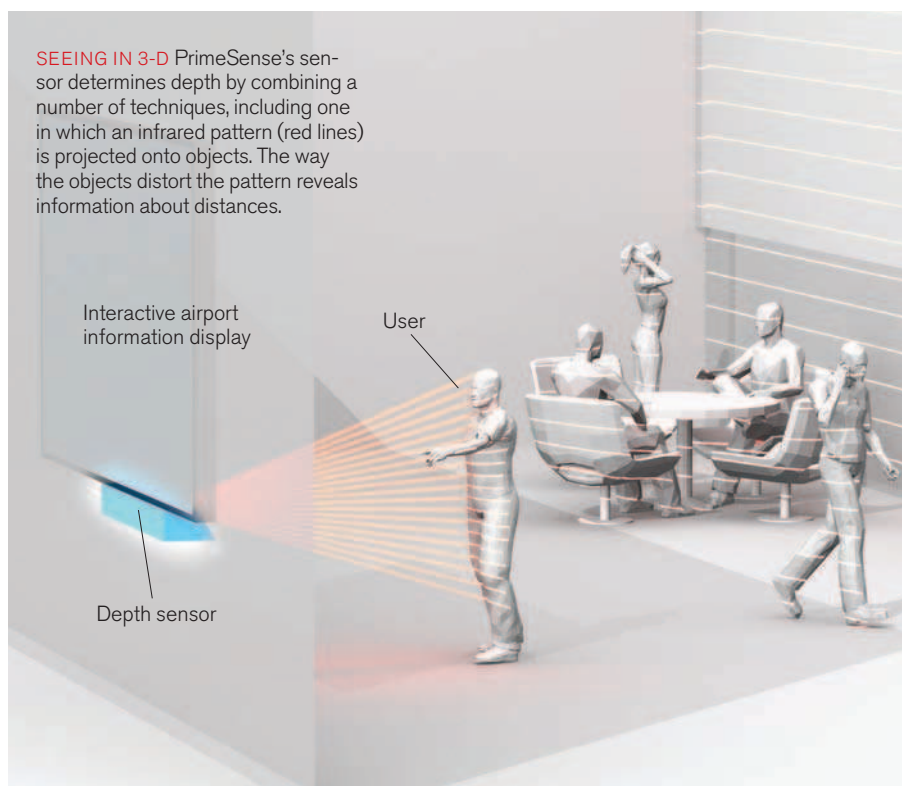
How do you issue complex commands to a computer without touching it? It's a crucial issue now that televisions are connected to social networks and cars are fitted with computerized systems for communication, navigation, and entertainment. So Alexander Shpunt has designed a 3-D vision system that lets anyone control a computer just by gesturing in the air.

Shpunt spent five years developing the system at Tel Aviv-based PrimeSense, and Microsoft adopted the technology to power its popular Kinect controller for the Xbox

360 game console. Players can use it to direct characters with their bodies alone—no need for the wands, rings, gloves, or colored tags that previous gestural interfaces relied on to detect the user's movements.

The key to dispensing with those props was getting the computer to see the world in three dimensions, rather than the two captured by normal cameras. Sensing depth makes it relatively easy to distinguish, say, an arm from a table in the background, and then track the arm's movement.

Shpunt recalls that when he started developing his system there were a few



SEEING IN 3-D PrimeSense's sensor determines depth by combining a number of techniques, including one in which an infrared pattern (red lines) is projected onto objects. The way the objects distort the pattern reveals information about distances.

ALEXANDER SHPUNT

(PrimeSense) Gestural interfaces will make it easier to control televisions, cars, and information displays.

OTHERS WORKING ON GESTURAL INTERFACES

Jonny Cheung Lee, Google, Mountain View, California

Alex Kipman, Microsoft, Redmond, Washington

Oblong, Los Angeles

ways to sense depth—primarily “time of flight” (determining distance from a sensor by measuring how long it takes light or sound to bounce off an object) and “structured light” (projecting patterns of light onto objects and analyzing how the patterns are distorted by the object’s surface). Although there was a lot of academic activity and a few companies built prototypes, there was “nothing really mature” that could be mass-produced, he says. Instead, he built his own system, cobbling together an approach that borrowed from those two techniques as well as stereoscopy—comparing images of the same scene from two different viewpoints.

The Kinect is only the beginning of what Shpunt believes will be a gestural-interface revolution. A small army of hackers, encouraged by PrimeSense, is already retooling the controller to other ends. Researchers at Louisiana State University have rigged a helmetless, gloveless virtual-reality system out of a Kinect unit and an off-the-shelf 3-D TV set. In Australia, a logistics software firm quickly put together a gesture-controlled system for monitoring air traffic. Further real-world applications are easy to imagine, says Shpunt: gaze-tracking heads-up controls for automobiles, touchless interactive displays for shopping malls and airports.

For now, Shpunt is working with computer maker Asus to build gestural controls for today’s increasingly complex and network-connected televisions—essentially turning a TV into a giant iPad that can be operated from the couch without a remote control. —*Julian Dibbell*



DECODING CANCER
Elaine Mardis uses sequencing to study the genomes of diseased cells.

Deciphering the genetics behind the disease

Cancer Genomics

In the fall of 2006, a new machine arrived at what’s now known as the Genome Institute at Washington University in St. Louis. It was capable of reading DNA a thousand times as quickly as the facility’s earlier machines, and at far less cost. Elaine Mardis, the center’s codirector, immediately began using it to sequence cancer tissues, scouring their DNA for mutations. Just five years later, Mardis and her collaborators have sequenced both cancerous and healthy tissue from several hundred patients and identified tens of thousands of mutations. Some of the findings have led to

new approaches to treating cancer, while others have opened new avenues of research.

Cancer develops when cells accumulate genetic mistakes that allow them to grow and divide faster than healthy cells. Identifying the mutations that underlie this transformation can help predict a patient’s prognosis and identify which drugs are most likely to work for that patient. The information could also identify new targets for cancer drugs. “In a single patient, you have both the tumor genome and the normal genome,” Mardis says. “And you can get at answers much more quickly by comparing the two.”

In 2008, Mardis and her team became the first to publish the sequence of a cancer genome, derived by comparing the DNA of healthy and cancerous cells in a patient with a bone marrow cancer called AML. Further studies have suggested that patients with mutations in a particular gene may fare better with bone marrow transplants than with traditional chemotherapy, a less risky treatment that physicians usually try first. Mardis predicts that soon all AML patients will be genetically tested, allowing their physicians to make more informed decisions about treatment.

As the cost and speed of DNA sequencing have dropped—Mardis estimates that sequencing genomes from a patient's cancerous and healthy tissue today costs about \$30,000, compared with \$1.6 million for the first AML genome—the technology is being applied to oncology more broadly. Research groups have now sequenced the genomes of multiple cancers, and in a handful of cases, they have used the results to guide treatment decisions for a patient (see “Cancer’s Genome,” *January/February 2011*). A few companies are now offering cancer genome analysis to researchers, and at least one is planning to offer the service to physicians and patients.

The decreasing cost of sequencing also means that Mardis can use the technology in drug development and testing. Her latest project is part of a clinical trial assessing hormone therapy for breast cancer. She has developed a preliminary genetic profile of cancers most likely to respond to a popular set of drugs called aromatase inhibitors, which are given to most breast cancer patients whose tumor cells have estrogen receptors on the surface. The goal is to identify the patients who will benefit from the drugs and those who won't. (Preliminary evidence suggests that only about half the patients in the trial respond to the drugs.)

Understanding cancer genomes isn't easy. Mardis's team had to invent techniques to distinguish the rare cancer mutations from the mistakes that routinely

occur when sequencing DNA. And scientists must figure out which mutations are actually driving the growth of the tumors and which are harmless. Then comes what might be the most challenging part: determining *how* the mutations trigger cancer. Mardis says she is leaving that challenge to the scientists around the world who are working to understand the mutations that she and others have identified. “It's really gratifying to see others pick that up,” she says. —*Emily Singer*

ELAINE MARDIS

(Washington University, St. Louis)
Sequencing the DNA of cancer cells is leading to new ways to treat patients.

OTHERS WORKING ON CANCER GENOMICS

Sam Aparicio, BC Cancer Agency, Vancouver

Todd Golub, Broad Institute, Cambridge, Massachusetts

Mike Stratton, Wellcome Trust Sanger Institute, Hixton, U.K.

High-energy cells for cheaper electric cars Solid-State Batteries

Ann Marie Sastry wants to rid electric vehicles' battery systems of most of the stuff that doesn't store energy, such as cooling devices and supporting materials within the battery cells. It all adds up to more than half the bulk of typical lithium-ion-based systems, making them cumbersome and expensive. So in 2007, she founded a startup called Sakti3 to develop solid-state batteries that don't require most of this added bulk. They save even more space by using materials that store more energy. The result could be battery systems half to a third the size of conventional ones.

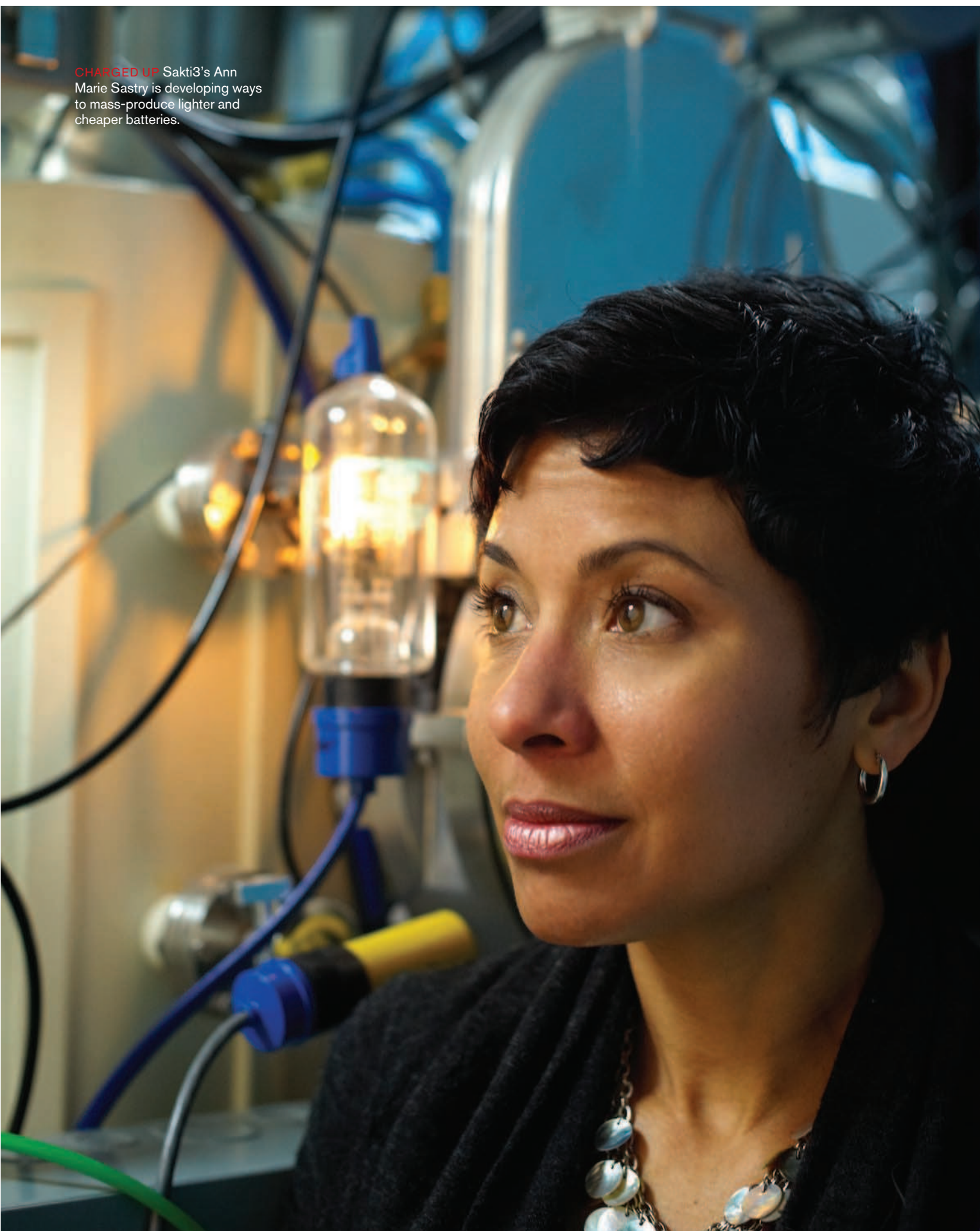
Cutting the size of a battery system in half could cut its cost by as much as half, too. Since the battery system is the most expensive part of an electric car (often costing as much as \$10,000), that would make electric cars far cheaper. Alternatively, manufacturers could keep the price constant and double the 100-mile range typical of electric cars.

The limitations of the lithium-ion batteries used in electric cars are well known.

“Most liquid electrolytes are flammable. The cathode dissolves,” says Sastry. Keeping the electrolyte from bursting into flames requires safety systems. And to extend the electrode's lifetime and prevent heat buildup, the battery must be cooled and prevented from ever fully charging or discharging, resulting in wasted capacity. All this adds bulk and cost. So Sastry wondered if she could make a battery that simply didn't need this much management.

Sastry's solid-state batteries are still based on lithium-ion technology, but they replace the liquid electrolyte with a thin layer of material that's not flammable. Solid-state batteries are also resilient: some prototypes demonstrated by other groups can survive thousands of charge-discharge cycles. And they can withstand high temperatures, which will make it possible to use materials that can double or triple a battery's energy density (the amount of energy stored in a given volume) but that are too dangerous or unreliable for use in a conventional lithium-ion battery.

CHARGED UP Sakti3's Ann Marie Sastry is developing ways to mass-produce lighter and cheaper batteries.



To make solid-state batteries that are practical and inexpensive to produce, Sastry has written simulation software to identify combinations of materials and structures that will yield compact, reliable high-energy devices. She can simulate these materials and components precisely enough to accurately predict how they will behave when assembled together in a battery cell. She is also developing manufacturing techniques that lend themselves to mass production. “If your overall objective is to change the way people drive, your criteria can no longer only be the best energy density ever achieved or the greatest number of cycles,” she says. “The ultimate criterion is affordability, in a product that has the necessary performance.”

Although it may be several years before the batteries come to market, GM and other major automakers, such as Toyota, have already identified solid-state batteries as a potentially key component of future electric vehicles. There’s a limit to how much better conventional batteries can get, says Jon Lauckner, president of GM Ventures, which pumped over \$3 million into Sakti3 last year. If electric vehicles are ever to make up more than a small fraction of cars on the road, “something fundamental has to change,” he says. He believes that Sakti3 is “working well beyond the limits of conventional electrochemical cells.”

Sastry is aware that success isn’t guaranteed. Her field is something of a technological battleground, with many different approaches competing to power a new generation of cars. “None of this is obvious,” she says. —*Kevin Bullis*

ANN MARIE SASTRY

(Sakti3) Smaller and lighter lithium batteries will make electric vehicles more competitive.

OTHERS WORKING ON SOLID-STATE BATTERIES

Planar Energy, Orlando, Florida
Seoo, Berkeley, California
Toyota, Toyota City, Japan

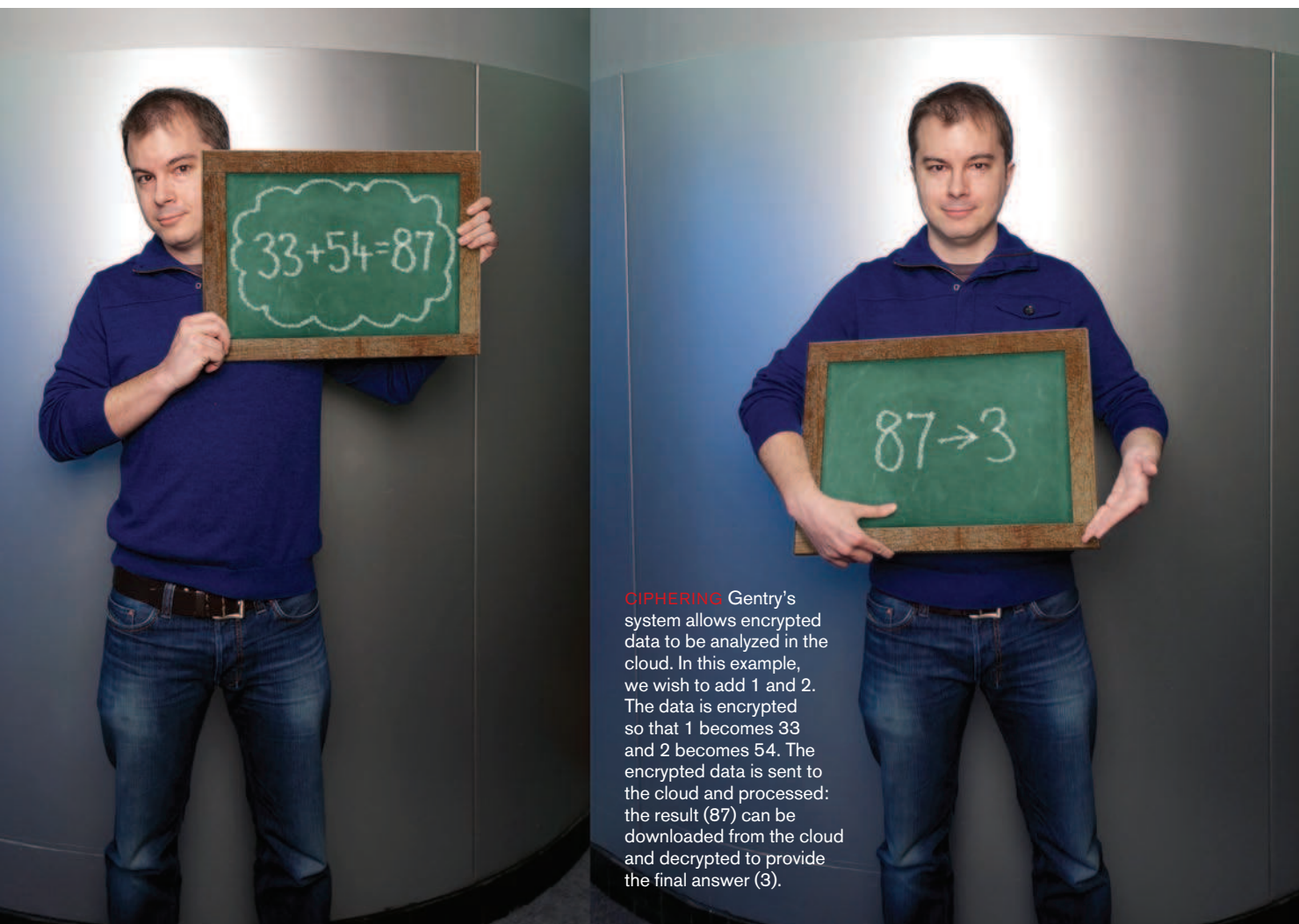


Making cloud computing more secure Homomorphic Encryption

Craig Gentry is creating an encryption system that could solve the problem keeping many organizations from using cloud computing to analyze and mine data: it’s too much of a security risk to give a public cloud provider such as Amazon or Google access to unencrypted data.

The problem is that while data can be sent to and from a cloud provider’s data center in encrypted form, the servers that

power a cloud can’t do any work on it that way. Now Gentry, an IBM researcher, has shown that it *is* possible to analyze data without decrypting it. The key is to encrypt the data in such a way that performing a mathematical operation on the encrypted information and then decrypting the result produces the same answer as performing an analogous operation on the unencrypted data. The correspondence between the oper-



CIPHERING Gentry's system allows encrypted data to be analyzed in the cloud. In this example, we wish to add 1 and 2. The data is encrypted so that 1 becomes 33 and 2 becomes 54. The encrypted data is sent to the cloud and processed: the result (87) can be downloaded from the cloud and decrypted to provide the final answer (3).

ations on unencrypted data and the operations to be performed on encrypted data is known as a homomorphism. “In principle,” says Gentry, “something like this could be used to secure operations over the Internet.”

With homomorphic encryption, a company could encrypt its entire database of e-mails and upload it to a cloud. Then it could use the cloud-stored data as desired—for example, to search the database to understand how its workers collaborate. The results would be downloaded and decrypted without ever exposing the details of a single e-mail.

Gentry began tackling homomorphic encryption in 2008. At first he was able to perform only a few basic operations on encrypted data before his system started producing garbage. Unfortunately, a task

like finding a piece of text in an e-mail requires chaining together thousands of basic operations. His solution was to use a second layer of encryption, essentially to protect intermediate results when the system broke down and needed to be reset.

“The problem of how to create true homomorphic encryption has been debated for more than 30 years, and Craig was the first person who got it right and figured out how to make the math work,” says Paul Kocher, the president of the security firm Cryptography Research. However, Kocher warns, because Gentry’s scheme currently requires a huge amount of computation, there’s a long way to go before it will be widely usable.

Gentry acknowledges that the way he applied the double layer of encryption was “a bit of a hack” and that the system

CRAIG GENTRY

(IBM) A secure way to process data could encourage more enterprises to use cloud computing.

OTHERS WORKING ON HOMOMORPHIC ENCRYPTION

Marten van Dijk, MIT, Cambridge, Massachusetts

Eleanor Reiffel, Fuji Xerox Palo Alto Research Laboratory, California

Nigel Smart, Bristol University, U.K.

runs too slowly for practical use, but he is working on optimizing it for specific applications such as searching databases for records. He estimates that these applications could be ready for the market in five to 10 years. —*Erica Naone*

This computationally intensive 3-D animation software appears to be running on a tablet but is actually running on OnLive's remote servers.



Bringing high-performance software to mobile devices

Cloud Streaming

In the Silicon Valley conference room of OnLive, Steve Perlman touches the life-like 3-D face of a computer-generated woman displayed on his iPad. Swiping the screen with his fingers, Perlman rotates her head; her eyes move to compensate, so that she continues to stare at one spot. None of this computationally intensive animation and visualization is actually taking place on the iPad. The device isn't powerful enough to run the program responsible—an expensive piece of software called Autodesk Maya.

WINNI WINTERMEYER

Rather, Perlman's finger-swipe inputs are being sent to a data center running the software. The results are returned as a video stream that seems to respond instantaneously to his touch.

To make this work, Perlman has created a way of compressing a video stream that overcomes the problems marring previous attempts to use mobile devices as remote terminals for graphics-intensive applications. The technology could make applications such as sophisticated movie-editing or architectural-design tools accessible on hundreds of millions of Internet-connected tablets, smart phones, and the like. And not only professional animators and architects would benefit. For consumers, it will allow streaming movies to be fast-forwarded and rewind in real time, as with a DVD player, while schools anywhere could gain easy access to software. "The long-term vision is actually to move all computing out to the cloud," says Perlman, OnLive's CEO.

Perlman's biggest innovation is dispensing with the buffers that are typically used to store a few seconds or minutes of streaming video. Though buffers allow time for any lost or delayed data to be re-sent before it's needed, they create a lag that makes it impossible to do real-time work. Instead, Perlman uses various strategies to fill in or hide missing details—in extreme cases even filling in entire frames by extrapolating from frames received earlier—so that the eye does not detect a problem should some data get lost or delayed. The system also continually checks the network connection's quality, increasing the amount of video compression and decreasing bandwidth requirements as needed. To save precious milliseconds, Perlman has even negotiated with Internet carriers to ensure that data from his servers is carried directly on high-speed, high-capacity Internet backbones.

The goal is to respond to user inputs within 80 milliseconds, a key threshold for visual perception. Reaching that threshold is crucial for a broad range of applica-

tions, says Vivek Pai, a computer scientist at Princeton University: "If you see a delay between what you are doing and the result of what you are doing, your brain drifts off."

Perlman founded OnLive in 2007 to commercialize his streaming technology, and last year he launched a subscription service offering cloud-based versions of popular action games, a particularly demanding application in terms of computing power and responsiveness. But games are just a start—OnLive's investors include movie studio Warner Brothers and Autodesk, which, besides Maya, also makes CAD software for engineers and designers. Perlman believes

STEVE PERLMAN

(OnLive) Mobile devices will be able to access powerful graphical applications running in data centers.

OTHERS WORKING ON CLOUD STREAMING

Cisco, San Jose, California
Mental Images, Berlin, Germany
Netflix, Los Gatos, California

that eventually, "any mobile device will be able to bring a huge level of computing power to any person in the world with as little as a cellular connection." —*David Talbot*

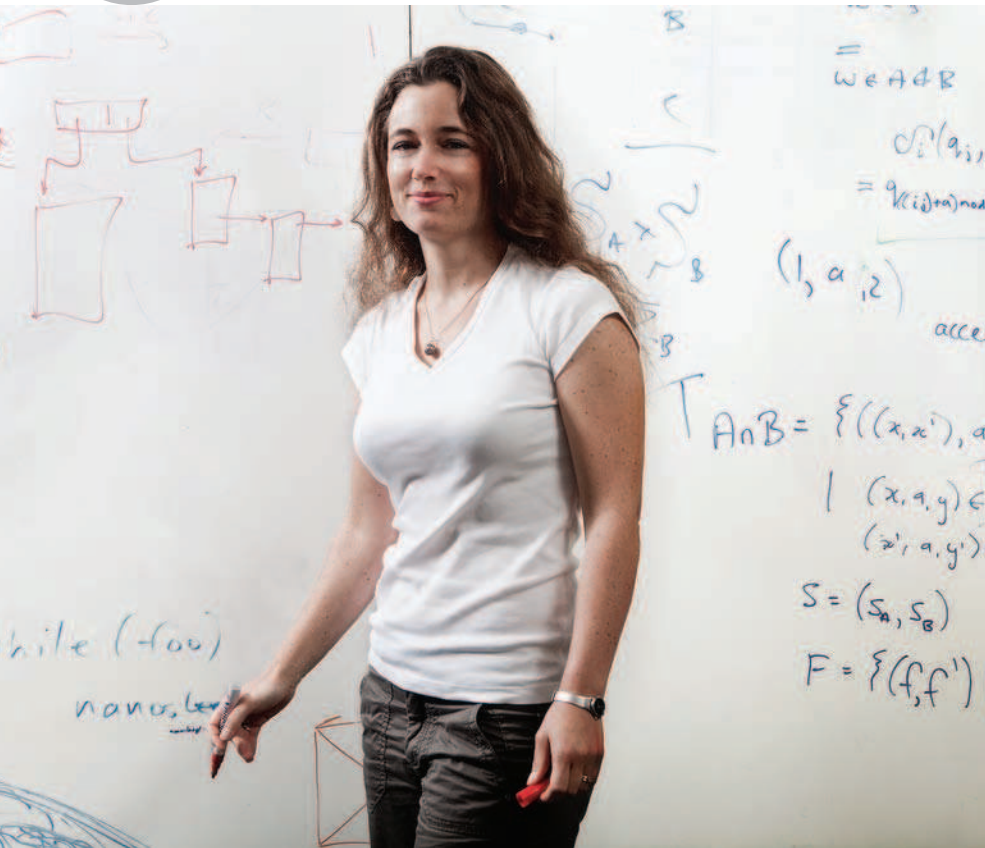
Making critical software safer Crash-Proof Code

When a computer controls critical systems in vehicles and medical devices, software bugs can be disastrous: "unnecessarily risky" programs could put lives in danger, says June Andronick, a researcher at NICTA, Australia's national IT research center. As a result of one recently discovered software vulnerability, she notes by way of example, "a car could be controlled by an attack on its stereo system." She is trying to reduce these risks by making the most important part of an operating system—the core, or kernel—in such a way that she can prove it will never crash.

The currently favored approach to creating reliable software is to test it under as many conditions as time and imagination allow. Andronick instead is adapting a technique known as formal verification, which microchip designers use to check their designs before making an integrated circuit: they create a mathematical representation of the chip's subsystems that can be used to prove that the chip will behave as intended

for all possible inputs. Until now, formal verification was considered impractical for large programs such as operating systems, because analyzing a representation of the program code would be too complicated. But in a computing and mathematical tour de force, Andronick and her colleagues, working in Gerwin Klein's lab at NICTA, were able to formally verify the code that makes up most of the kernel of an operating system designed for processors often found embedded in smart phones, cars, and electronic devices such as portable medical equipment. Because this code is what ultimately passes software instructions from other parts of the system to hardware for execution, bullet-proofing it has a major impact on the reliability of the entire system.

"The work is hugely significant," says Lawrence Paulson, a computer science professor at the University of Cambridge. Beyond showing that there's no bug in the kernel that could cause it to crash, he says, the verification guarantees that the kernel



FAIL-SAFE June Andronick uses mathematical analysis to create crash-proof software.

will perform, without error, every function it was programmed to perform.

The task was made a little easier by the choice to develop a so-called microkernel. Microkernels delegate as many functions as possible—such as handling input and output—to software modules outside the kernel. Consequently, they are relatively small—in this case, about 7,500 lines of C code and 600 lines of assembler. “That’s

really small for a kernel, but really large for formal verification,” Andronick says. The analysis was targeted at the thousands of lines of C code; new software and mathematical tools had to be developed for the task. The kernel was released in February, and the team is working on another version designed for the popular line of x86 processor chips.

Andronick doesn’t expect that the technique will scale to much larger software, but she doesn’t think it has to. Using verified code in key subsystems would allow developers to make sure that bugs in less rigorously examined programs—such as those used to interface with a car stereo—can’t affect critical hardware. It could also prevent a computer from locking up if it encounters a problem. Andronick wants more software developers to embrace formal verification “in fields where safety and security really matter,” she says. “We show that it is possible.” —*William Bulkeley*

JUNE ANDRONICK

(NICTA) A crash-proof operating system means more reliable computers in critical systems such as medical devices.

OTHERS WORKING ON CRASH-PROOF CODE

Xinyu Feng, University of Science and Technology of China, Suzhou
Chris Hawblitzel, Microsoft Research, Redmond, Washington
Zhong Shao, Yale University, New Haven, Connecticut

A more precise way to read DNA will change how we treat disease

Separating Chromosomes

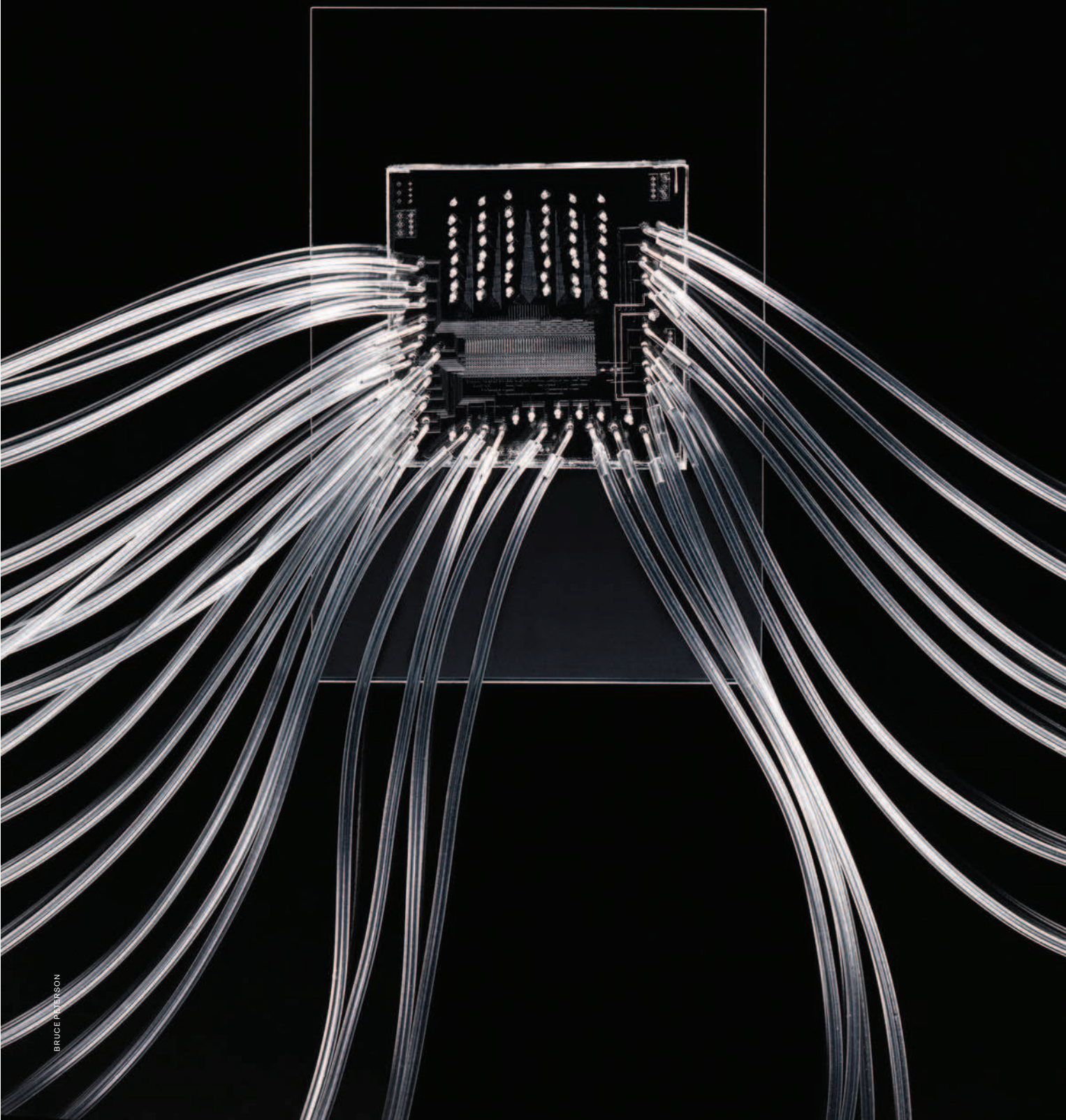
The clear rubber chip sitting under a microscope in Stephen Quake’s lab is a complex maze of tiny channels, chambers, and pumps, hooked up to thin plastic tubes that supply reagents and control 650-plus minuscule valves. Using this microfluidic chip, Quake, a biophysicist at Stanford University, has engineered a way of obtaining data that’s missing from nearly all human genome sequences: which member of a pair of chromosomes a gene belongs to.

Technology that makes it easier to identify the variations between chromosomes could have a huge impact on fundamental genomic research and personalized medicine. “This is definitely the next frontier,” says Nicholas Schork, a statistical geneticist at the Scripps Research Institute. Right now, he says, “we’re missing out on all sorts of biological phenomena that occur as a result of humans’ having [paired chromosomes].”

When scientists sequence human genomes, they largely ignore the fact that chromosomes come in pairs, with one copy inherited from the mother and one from the father. (The Y chromosome, which determines gender, is the exception.) Standard techniques blend genetic data from the two chromosomes to yield a single sequence.

Quake’s alternative is to physically separate chromosomes before genomic analysis. Cells are piped into the chip; when Quake

CHROMOSOME CHIP This matchbox-size device uses tiny valves, channels, and chambers to separate the 23 pairs of chromosomes in the human genome so they can be analyzed individually.



spots one that's preparing to divide (a stage at which the chromosomes are easier to manipulate), he traps the cell in a chamber and bursts its membrane, causing the chromosomes to spill out. They are randomly distributed into 48 smaller chambers. While it is possible for more than one chromosome to end up in a single chamber, it's very unlikely that a chromosome will end up with its pair. Using standard techniques, the chromosomes are then sequenced or screened for genetic variants.

Other groups have pursued different strategies to sequence individual chromosomes. But Quake thinks his has an advantage because it doesn't rely on decoding and reconstructing chromosomes from a mixed pool of DNA fragments, as others do. "By the way we physically prepare the sample, we know [the result is] right," he says.

If costs can come down enough, Quake's technique will be widely used, says Meredith Yeager, a senior scientist at the National Cancer Institute's Core Genotyping Facility. The ability to routinely tell where genetic variants lie on different chromosomes "really is a big deal," Yeager says. "Context matters."

For example, if testing detects two separate mutations in a disease-related gene, it's now impossible to tell whether one chromosome has both mutations or each chromosome has one. A patient who has at least one good copy of the gene is much more likely to escape the disease or experience it in a relatively mild form. Whether the aim is to predict responses to an asthma drug or to find better matches for bone marrow transplants,

the accuracy of personalized medicine could eventually hinge on understanding the variation between chromosomes.

Fluidigm, the South San Francisco company that Quake cofounded in 1999 to commercialize microfluidic chips, is now looking at ways to automate the chromosome separation chip so that it doesn't require so much

expertise to use. Quake hopes to discover "something really interesting" about human diversity or the region of the genome that defines immune system responses. This region has been difficult to understand because it has so much genetic variation, and scientists lacked a tool to study it carefully—until now. —*Ingfei Chen*

Designing new genomes could speed the creation of vaccines and biofuel-producing bacteria

Synthetic Cells

The bacteria growing on stacks of petri dishes in Daniel Gibson's lab are the first living creatures with a completely artificial genome. The microbes' entire collection of genes was edited on a computer and assembled by machines that create genetic fragments from chemicals and by helper cells that pieced those fragments together. Gibson hopes that being able to design and create entire genomes, instead of just short lengths of DNA, will dramatically speed up the process of engineering microbes that can carry out tasks such as efficiently producing biofuels or vaccines.

Until last year, biologists hadn't been able to make large enough pieces of DNA to create an entire genome; though living cells routinely make long stretches of DNA, a DNA synthesis machine can't do the same. In May, Gibson and his colleagues at the J. Craig Venter Institute announced their solution to this problem. Gibson used yeast cells to stitch together thousands of fragments of DNA made by a machine, pooled the longer pieces, and repeated the process until the genome was complete. Next he inserted the genome into bacterial cells that were about to divide and grew the bacteria

in a medium hostile to all cells except the ones harboring the synthetic genome.

"When we began in 2004," he says, "assembling a complete bacterial genome didn't seem like an easy thing to do"—even though the Venter Institute researchers started with one of the smallest bacterial genomes that have been sequenced, that of a mycoplasma. After finally overcoming the technical hurdles involved, Gibson says, creating the synthetic cell itself was exciting but almost anticlimactic. Going from computer screen to bacterial colony now seems easy.

Gibson has also developed a faster, yeast-free way to assemble large pieces of DNA in a bottle. His colleagues are using these methods to rapidly synthesize the viral DNA needed to speed up the production

STEPHEN QUAKE

(Stanford University) Identifying variations between paired chromosomes will make genomics much more accurate.

OTHERS WORKING ON SEPARATING CHROMOSOMES

Complete Genomics, Mountain View, California

Nicholas Schork, Scripps Research Institute, San Diego, California

Jay Shendure, University of Washington

DANIEL GIBSON

(J. Craig Venter Institute) Designing and creating genomes from scratch could expand the possibilities of genetic engineering.

OTHERS WORKING ON SYNTHETIC CELLS

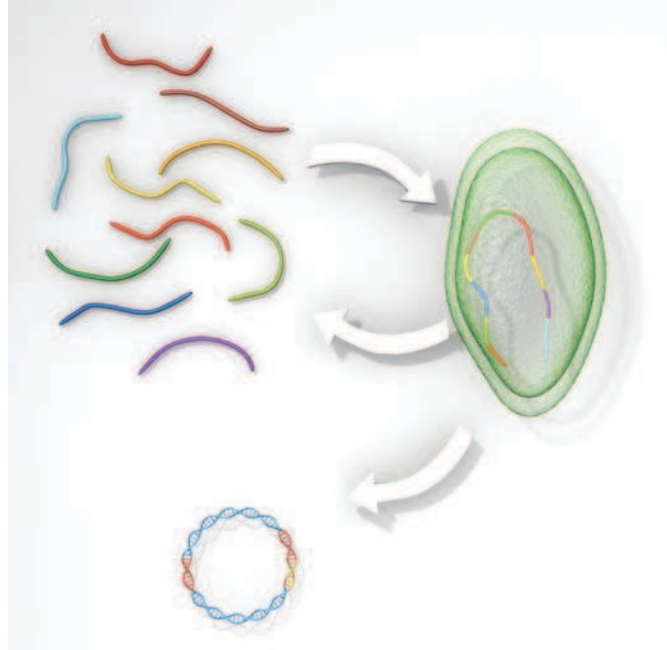
Jim Collins, Boston University

Jay Keasling, UC Berkeley, California

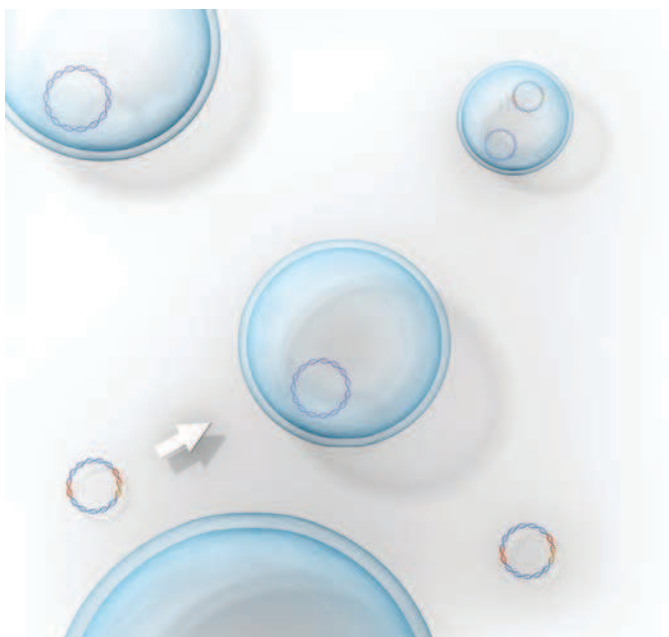
Chris Voigt, UC San Francisco



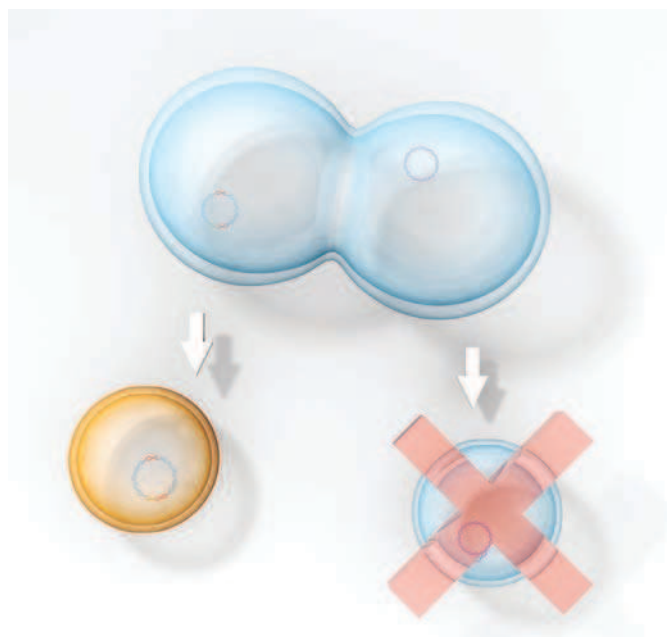
1: Bacterial genomes take the form of rings of DNA. An artificial genome is designed on a computer, including a sequence that “watermarks” the genome (red arc) and one that confers resistance to antibiotics (yellow arc). The genome is then synthesized as 1,078 overlapping DNA fragments.



2: Yeast cells stitch together 10 sequential fragments at a time. The longer strands are in turn stitched together by other yeast cells, and the process is repeated until copies of the whole genome are assembled.



3: The synthetic genomes are added to a culture of bacteria. Some of the bacterial cells absorb the synthetic genomes alongside their own.



4: When the bacterial cells divide, each daughter inherits one genome. An antibiotic is used to kill cells that have the natural genome, leaving a colony of bacteria with the synthetic genome.

of influenza vaccines. The nonprofit Venter Institute is working with Synthetic Genomics, a company that commercializes work done at the institute, to develop products.

The creation of the synthetic cell is part of an effort to design a “minimal cell” containing only the most basic genome required for life. Gibson and his colleagues at the Venter Institute believe that synthetic

biologists could use this minimal cell as the basis for cells that efficiently produce bio-fuels, drugs, and other industrial products.

Right now, Gibson’s technique for incorporating his synthetic genome into living cells works only with mycoplasmas, which are useful for experimentation but not for industrial purposes. If Gibson can adapt this system to work with a broader group

of bacteria, it could be used to speed up the process of engineering microbes that make a wide variety of products. At least two major challenges remain: developing appropriate recipient cells for genome transplants, and finding ways of working with even larger pieces of DNA. “We’re still in the early stages,” he says, “and we don’t know what the limits are.” —*Katherine Bourzac*

A large, terraced open-pit mine with a turquoise reservoir in the foreground and mountains in the background. The mine's terraces are made of dark, layered rock. The reservoir is a vibrant turquoise color, contrasting with the brown and grey of the mine. In the foreground, there is a pile of loose rocks and debris. A dirt road runs along the right side of the mine. The background shows more mountains under a clear sky.

The Rare-Earth Crisis

Today's electric cars and wind turbines rely on a few elements that are mined almost entirely in China. Demand for these materials may soon exceed supply. Will this be China's next great economic advantage?

By KATHERINE BOURZAC

Photographs by DANIEL HENNESSY



MIGHTY MINE This 50-acre mine on the eastern edge of California's Mojave Desert was once the world's leading supplier of rare-earth metals. Water pooled at the bottom of the mine while it lay idle after being shut down a decade ago.

On the eastern edge of the Mojave Desert, an hour's drive southwest of Las Vegas in Mountain Pass, California, lies a 1.4-billion-year-old deposit of cerium, neodymium, and other metals that is the richest source of rare-earth elements in the United States. Beside hills populated by cacti, Joshua trees, and wandering tortoises is a vast waste dump of tan and white rocks that was built up over more than 50 years of production at a 50-acre open-pit mine here. The mine was once the world's biggest producer of these metals, which are crucial to such diverse products as computer hard drives, compact fluorescent light bulbs, and the magnets used in electric vehicles' motors. And the site still holds enough of them to mine for at least another 30 years. But in 2002 it was shut down, owing to severe environmental problems and the emergence of Chinese producers that supplied the metals at lower cost. The mine sat idle for a decade.

With worldwide demand for the materials exploding, the site's owner, Molycorp Minerals, restarted mining at Mountain Pass last December. It is now the Western Hemisphere's only producer of rare-earth metals and one of just a handful outside of China, which

currently produces 95 percent of the world's supply. Last September, after China stopped exporting the materials to Japan for two months, countries around the world began scrambling to secure their own sources. But even without Chinese restrictions and with the revival of the California mine, worldwide supplies of some rare earths could soon fall short of demand. Of particular concern are neodymium and dysprosium, which are used to make magnets that help generate torque in the motors of electric and hybrid cars and convert torque into electricity in large wind turbines. In a report released last December, the U.S. Department of Energy estimated that widespread use of electric-drive vehicles and offshore wind farms could cause shortages of these metals by 2015.

What would happen then is anyone's guess. There are no practical alternatives to these metals in many critical applications requiring strong permanent magnets—materials that retain a magnetic field without the need for a power source to induce magnetism by passing an electric current through them. Most everyday magnets, including those that hold notes on the fridge, are permanent magnets. But they aren't very strong, while those made from rare earths

REBUILDING Processing equipment at Molycorp Minerals' mine in California, pictured here in December 2010, is currently being rebuilt. The equipment shown includes machinery used to crush and dissolve rocks from the mine and extract and dry rare-earth oxides.



are tremendously so. Alloys of neodymium with iron and boron are four to five times as strong by weight as permanent magnets made from any other material. That's one reason rare-earth magnets are found in nearly every hybrid and electric car on the road. The motor of Toyota's Prius, for example, uses about a kilogram of rare earths. Offshore wind turbines can require hundreds of kilograms each.

New mining activity, not only at Mountain Pass but also in Australia and elsewhere, will increase supplies—but not enough to meet demand for certain critical metals, particularly dysprosium, in the next few years. And the limited capacity of the new mining operations is not the only problem. Because rare earths make such excellent magnets, researchers have put little effort since the early 1980s into improving them or developing other materials that could do the job. Few scientists and engineers outside China work on rare-earth metals and magnet alternatives. Inventing substitutes and getting them into motors will take years, first to develop the scientific expertise and then to build a manufacturing infrastructure. The United States “lost expertise” when its mines closed and magnet

manufacturing relocated to Asia to be near operating mines and less expensive labor, says George Hadjipanayis, chair of physics and astronomy at the University of Delaware. As a result, there were few incentives for researchers or companies to work on magnets. Now, he says, “there is not much funding and no industry around.”

REBORN

Rare-earth metals, despite the name, are relatively abundant in Earth's crust. The 16 naturally occurring rare earths are usually found mixed together in deposits that often contain radioactive elements as well—and separating the metals requires costly processes that produce a stew of toxic pollutants. “We know what the [total] concentration of rare earths is in all areas of the deposit,” says Molycorp mine manager Rocky Smith, standing on one of the tiers carved into the 800-foot-deep pit and pointing out an ore-laden rock; it's tinged mauve with bastnäsite, a mineral that contains a mixture of rare earths. But knowing where the rare earths are throughout the site and getting the individual metals out of the ore are two different things.





The first step in extracting rare-earth oxides from the surrounding rock is to crush the rocks and grind them into a fine powder. This is passed through a series of tanks, where the rare-earth elements float to the top. Unwanted minerals sink to the bottom, and this hazardous waste material, called tailings, is sent to ponds for storage. Meanwhile, the resulting concentrate of rare-earth metals is roasted in kilns and then dissolved in acid. The fraction of the resulting slush that contains rare earths, in the form of mixed metal oxides, is removed. Finally, the solvent is neutralized.

The reaction generates a lot of salt: when the Mountain Pass mine was running at full capacity in the 1990s, it produced as much as 850 gallons of salty wastewater every minute, every day of the year. This waste also contained radioactive thorium and uranium, which collected as scale inside the pipe that delivered the wastewater to evaporation ponds 11 miles away. Several times in the 1990s, cleaning operations intended to remove the built-up scale caused the pipeline to burst, spilling hundreds of thousands of gallons of hazardous waste into the desert. The state of California ordered Molycorp, which was then a unit of the oil company Unocal, to clean up the waste. In 2002, the company, already struggling to make a profit, ran out of space to store its tailings and failed to secure a permit to build a new storage facility. The mine shut down.

Chevron bought Unocal in 2005, acquiring Molycorp and the Mountain Pass mine along with it. In 2008, a group of private investors bought the mine and formed Molycorp Minerals, which has been developing processing technologies that it says will eliminate the need for evaporation ponds and pipelines. In 2009, Molycorp began processing stockpiled bastnäsite to extract the mixed rare-earth mineral didymium. Last summer the company went

RARE ORE Rocks dislodged by blasts at Mountain Pass (left) contain the rare-earth mineral bastnäsite. The rocks are crushed and dissolved and the slush is separated to produce didymium oxide (center), a mixture of oxidized light rare earths that requires further processing to make the pure neodymium metal required for magnets. Today, Molycorp ships bags of didymium oxide (right) to customers in Japan and elsewhere for processing.

public, and its stock price has soared. The U.S. rare-earth industry was reborn.

But a visit to Molycorp's processing facility shows that the resumption of mining at Mountain Pass will not solve all the supply problems. Inside a small warehouse where the rare-earth oxides are dried and packaged, Molycorp CEO Mark Smith dips his hand into a barrel to scoop up a handful of tan-colored powder. It's soft, like fine ash. This material is didymium oxide, a mixture of oxidized neodymium and praseodymium, elements far to the left on their row in the periodic table. The deposit at Mountain Pass, like other rare-earth deposits except a few in southern China, is richest in these lighter elements. They are fine for glass polishing and car batteries and for magnets that work at low temperatures. But to withstand the high temperatures in motors and turbines, magnets require the addition of dysprosium or terbium, which are heavy rare earths.

Another problem is that Molycorp is just beginning to rebuild the infrastructure needed to turn rare-earth ore into magnets. When mining operations left the United States, all that infrastructure followed. The purification of rare earths is now done almost exclusively in China, though Malaysia is building a new facility. And the magnet industry is now based largely in China and Japan. The Japanese company Hitachi Metals, which holds the necessary



patents to make rare-earth alloys and magnets, has entered into an agreement with Molycorp to make them in the United States. Molycorp will supply the neodymium, but to make heat-tolerant magnets, the company might have to acquire the additional heavy rare earths from somewhere other than its Mountain Pass mine—and it's hard to know where that might be.

LOOKING FOR LUCK

Though rare-earth purification is no longer done in the United States, it was invented here by Frank Spedding, the founder of the Ames National Laboratory in Iowa. In 1949, even before rare earths were used industrially, Spedding invented the first methods for separating them from one another; the technique grew out of his work on purifying uranium and thorium for the Manhattan Project. The Ames lab is still the only research center in the country with a significant emphasis on the materials.

Ames researcher Iver Anderson has no trouble demonstrating why rare-earth materials are so valuable in magnets. Extending his hand over his desk, palm side down, he shows that the field produced by a tiny piece of a broken neodymium magnet balanced on the back of his hand can make another neodymium magnet, the size of a penny, stick to his palm. Pairs of neodymium magnets much larger than this can break bones. Anderson then picks up a considerably heavier magnet, made of aluminum, nickel, iron, and cobalt. It barely holds onto the tip of a dangling paper clip.

Weak though this performance is, the material's magnetic properties show some promise, so Anderson's group is trying to improve them by tinkering with its structure, a mixture of nanoscale iron-cobalt needles separated by a matrix of nickel

and aluminum. Working from theoretical studies of the material, Anderson hopes to alter processing conditions so as to make the needles longer and align them better. "How long can we make the needles?" he wonders. "What if we put a humongous magnetic field on the sample—would it change their spacing, make them grow longer?"

The chief appeal of the magnet is that it contains no rare-earth metals. Still, even the Ames researchers seem uncertain that a material like this could ever take the place of rare-earth magnets. Since neodymium magnets were introduced in 1983, nothing has been developed that comes close to matching them. But, says Anderson, "you can get lucky."

The researchers are also working on ways to manufacture rare-earth magnets more efficiently. Currently, the magnetic materials are heated and compressed to form large, dense blocks that must then be cut to the desired shape. This process leaves behind piles of oxidized metal shavings called swarf, which is often contaminated with lubricants for the cutting blades. The impure swarf can't be integrated into new magnets, but finding a way to use it—or formulating the magnet materials in such a way that they can be molded rather than cut—would stretch the valuable elements further. "People are looking at 55-gallon drums full of this grinding waste, which looks like grayish-brown mud, wondering how to reclaim the rare earths out of all that swarf," says Anderson.

If the supply of rare earths falls short of demand in the coming years and no substitutes that approach their performance are found, makers of hybrid and electric cars will probably try to develop new motor designs that rely on induced rather than permanent magnetism, says Eric Rask, a researcher at Argonne National Laboratory. Before joining Argonne two years ago, Rask worked on the power-train system for General Motors' electric Volt, which uses a rare-earth permanent magnet. But, he says, "the reason permanent-magnet motors are used is that their efficiency is almost always higher in the range where you use it a lot—typically you can get more torque for a given supply of current."

Few experts express optimism that there will be enough rare-earth materials to sustain significant growth of clean energy technologies like electric cars and wind power, which need every possible cost and efficiency advantage to compete. "The writing is already on the wall," says Patrick Taylor, director of the Kroll Institute for Extractive Metallurgy at the Colorado School of Mines. "You want to develop this big new energy economy, but there's a limited supply and an ever-increasing demand." Asked how China gained its edge over the rest of the world, Taylor points out that most of the necessary expertise and industry began moving to that country nearly two decades ago. Back then, he adds, no one was even paying attention. **tr**

KATHERINE BOURZAC IS TECHNOLOGY REVIEW'S MATERIALS SCIENCE EDITOR.

You Are the Ad

Facebook has emerged from a privacy scandal to become online advertising's next great hope. Its goal: turning us all into marketers.

By ROBERT D. HOF

Three years ago 1-800-Flowers, long a pioneer in Internet marketing, became the first national florist to create a fan page on Facebook. It used the free page to build relationships with customers and sell selected products, but it spent very little money advertising on the site. In January, however, the company began buying a different kind of Facebook advertisement. "Sponsored stories," as they're called, let marketers pay to turn actions people take on Facebook into promotional content. When members click a thumbs-up button to signal that they "like" a product or brand, for example, a simple ad appears on their friends' pages: "Julia Smith likes 1-800-Flowers.com." Those friends can click a Like button on that ad, which then shows up on *their* friends' pages, and so on.

Thanks in part to those ads, the company now has more than 125,000 Facebook fans, more than twice as many as it had at the start of the year. Now, says 1-800-Flowers president Chris McCann, "We look at Facebook as core to our marketing program."

So do dozens of other major brands, including Ford, Procter & Gamble, Starbucks, and Coca-Cola. Suddenly, large companies are running multimillion-dollar ad campaigns on Facebook. Startups, such as the social-game maker Zynga and the daily-deal service Groupon, are mounting similar though smaller campaigns, and so are hundreds of thousands of local businesses, such as fitness salons and photographers. Facebook ads hauled in nearly \$2 billion in revenues last year, according to the business information service eMarketer, and a leaked document belonging to investor

Goldman Sachs revealed that the privately held company made a profit of about \$500 million in the same period. This year, revenues are on track to reach \$4 billion—making the \$75 billion valuation investors are placing on Facebook seem slightly less crazy.

It's a stunning performance for a company many observers thought would never make much money, let alone become a major force in advertising. (*We were wrong, too. See "Social Networking Is Not a Business," July/August 2008.*) But cofounder and CEO Mark Zuckerberg and his ad executives are just getting started. Chief operating officer Sheryl Sandberg and David Fischer, vice president of advertising and global operations, intend to create something quite different from the two dominant types of advertising online: the search (or keyword) ads on Google and the display (or banner and video) ads everywhere else on the Internet.

Most of the ads on Facebook today—little rectangles running down the right side of the page, each holding a tiny image and up to 160 characters of text—barely hint at the huge bet Sandberg and Fischer are making. Facebook aims to be not just a place to advertise but an entirely new way to advertise—one that uses the power of social networks to create and amplify brand messages. In essence, the company is pushing a highly charged version of word of mouth, long seen as the most valuable of all marketing because people view friends' recommendations as more credible than marketers'.

Conventional word of mouth reaches only a limited number of people. Facebook, where each of an estimated 600 million active

GABRIELA HASBUN

users is connected to an average of 130 friends, changes all that by lending personal recommendations enormous reach. After all, anything a user does on the site can be broadcast automatically to all that person's friends. "This is in many ways the Holy Grail of marketing: making your customers your marketers," says Sandberg, who joined Facebook in early 2008 after building up Google's ad sales operation from four people to 4,000. "For the first time, you can do word-of-mouth marketing at massive scale."

To put it another way, when we use Facebook we no longer just view the ad; we become the ad. It's a notion that disturbs some people, especially as Facebook continues to challenge social norms about privacy and use of personal data. Indeed, one reason advertisers love Facebook is that ads can be precisely targeted to specific audiences on the basis of their stated interests, location, "likes," and much more. "A lot of data is being harvested and monetized by Facebook and its advertisers, but users have no idea," says Jeff Chester, executive director of a nonprofit digital-marketing watchdog called the Center for Digital Democracy.

Zuckerberg believes that these new, more personal forms of marketing are the only way advertisers can adapt to the increasingly social nature of the Internet. On average, users spend more than six and a half hours a month on Facebook, significantly more time than they spend on other major sites—mostly because they are so engrossed in communicating with their friends. There's an implicit contract in social media that people not be interrupted by commercial pitches, just as it would be inappropriate to start hawking Tupperware without warning at a dinner party, suggests Ted McConnell, a former longtime P&G marketing executive who's now executive vice president of digital for the Advertising Research Foundation. This means the attention-grabbing kind of image-based advertising that still dominates television, magazines, and even major websites could be an artifact of one-way broadcast media—which is to say, all media that preceded the Internet.

On the Internet, not only can consumers talk back to advertisers, but they can talk to each other about products, services, and brands. Ford sought to harness that kind of activity last year when it unveiled its 2011 Explorer sport utility vehicle not at an auto show but on Facebook. "We wanted to avoid the traffic jam of the auto shows," says Scott Monty, Ford's head of social media. The company put up a teaser page on Facebook, with videos, photos, a sweepstakes to win a car, and, on the day of the "reveal," live chats with CEO Alan Mulally



SECOND ACT Sheryl Sandberg, Facebook's chief operating officer, joined the social-networking company from Google, where she ran its advertising business. Her goal is to build Facebook's ad business into something equally innovative.

and other executives. And it ran ads on Facebook encouraging people to "like" the Explorer. The result, according to the auto-website network Jumpstart Automotive Group: the share of SUV shoppers on Jumpstart sites who researched Fords jumped 52 percent, more than triple the increases other automakers saw after spending \$2.5 million apiece on 30-second televised Super Bowl ads.

SHINY NEW OBJECT

What sets Facebook apart from online rivals, especially Google, is that its advertising is aimed not at influencing immediate purchases but at branding, something online ads have never done very well. "We're not really demand fulfillment, when you've already figured out what you're going to buy—that's search," explains Sandberg, bounding up to a whiteboard to circle the bottom of a classic "marketing funnel," representing the stage at which a purchase is completed. Circling the top half of the funnel, where consumers become aware

of brands and consider buying their products, she adds: “We’re demand generation, before you know you want something.”

If she and Fischer can deliver on their plans, Facebook could capture significant chunks of the \$500 billion advertising market from television, now the dominant medium for brand marketing. Dwayne Chambers, chief marketing officer at Krispy Kreme, for instance, recently told *Advertising Age* that Facebook, where the doughnut company has more than three million fans, now looks like a more attractive place to advertise than TV.

It surely won’t move all its ads there right away, though. A lot of Facebook’s current advertising is anything but revolutionary. For one thing, even Facebook concedes that most of the ads aren’t yet very social. They may promote a brand or provide a link to a brand site, as other display ads do, but many still don’t carry friends’ recommendations or even a Like button. What’s more, many of the ads aren’t even used for branding; they merely try to get people to play a game or fill out an e-mail registration. Facebook’s ability to target audiences according to their interests and site activities makes these ads attractive enough to direct marketers, but it’s hardly unique: advertising networks run by Google, Yahoo, and others distribute similar ads to targeted audiences on thousands of websites.

Another challenge is that very few people click on Facebook ads. The analytics firm Webtrends recently estimated that these ads on average draw clicks only once every 2,000 times they’re viewed—about half the industry average for display advertising. Though ads with a friend’s name attract more clicks, the performance is still nowhere near that of Google ads, which on average get a click for every 50 times they’re viewed. That’s mostly due to the nature of search ads, which are served up to people who have often signaled their readiness to purchase with the very words they type into the search box. But the inescapable result is that Google still grossed more in a month in 2010 than Facebook did all year, even though people spent more time on Facebook.

Right now, many advertisers are embracing Facebook anyway—the returns are good enough, and they don’t want to be left behind. “Social media is the shiny new object,” says Jascha Kaykas-Wolff, VP of marketing for Involver, which supplies technology to help brands manage their social-media presence. But other advertisers remain wary, and for good reason. Advertising on social-networking pages means relinquishing a lot of control. An ad might be displayed alongside pictures of a college kid getting wasted, or a “sponsored story” on Facebook might turn out to republish negative feedback from a customer. “Buy an ad—you don’t get to write it,” Sandberg says, laughing at how such a pitch must sound to advertisers. Some marketers also want to be more creative with their ads than what’s permitted on Facebook, whose plain ad designs are intended to avoid annoying users. “I would like [ads] to be more eloquent and elegant,” says Seth Greenberg, Intuit’s vice president of global media and digital marketing.

If Facebook’s leaders hope to reinvent marketing in the age of social media, then, it’s clear they must still persuade marketers—as well as the people those marketers want to reach—that social marketing has real value. But its early efforts to develop this new form of marketing suggest how difficult this will be.

PRIVACY DEBACLE

On November 6, 2007, Mark Zuckerberg mounted a stage at a New York event space called Loft Eleven and declared, “The next hundred years will be different for advertising, and it starts today.” Engineers had been working day and night on a “completely new way of advertising online,” called Facebook Ads. Companies including Coca-Cola, Blockbuster, and CBS had already signed on. Advertisers would be able to set up free brand pages enabling people to become their “fans.” “Social ads” would combine actions posted by Facebook members, such as a purchase or a restaurant review, with the advertiser’s message. And a system called Beacon would post on the news feeds of a logged-in Facebook user’s friends whenever that user took an action on some 40 other websites, such as buying a movie ticket on Fandango or listing an item for sale on eBay.

“We’re not really demand fulfillment, when you’ve already figured out what you’re going to buy—that’s search. We’re demand generation, before you know you want something.”

People could opt out of Beacon on these individual partner sites, but that wasn’t enough to prevent a wave of outrage from privacy advocates and users. Some were furious, for example, to find their gift purchases broadcast to recipients. Coke, among other advertisers, quickly bowed out of Beacon. Within a month of the announcement, Zuckerberg apologized and changed the system to give users more control over how their actions were tracked. But the fallout was a big blow to Facebook’s strategy of using participants’ activities to target ads. Although Facebook’s revenues would hit \$300 million by the end of 2008, according to published accounts, they were dwarfed by those of its rival MySpace, whose banner ads and flashy homepage takeovers were widely estimated to have grossed \$600 million.

Nonetheless, Facebook kept focusing on ads that tapped its social graph, the term Zuckerberg used to describe the way relationships on the site could be mapped. It even gave users a chance

to click thumbs-up or thumbs-down buttons on ads. In August 2008 the company launched “engagement ads,” which prompted users to comment, sign up as a Facebook fan of the advertiser, or take part in a poll; those actions would show up in friends’ news feeds. Those ads were slow to catch on, but in 2009 Facebook added other features for marketers. Among them was a new design for brand pages that made them look more like user profile pages—implicitly turning brands into peers.

These efforts increased Facebook’s appeal to marketers without antagonizing users. After attending a January 2010 meeting between venture capitalists and P&G executives, David Hornik, a partner with August Capital, wrote that P&G had come to view Facebook as a “must-have for digital advertising and brand building” for which it was “willing to pay dearly.” The following month, in a powerful sign that Facebook was putting all its chips on social ads, the company not only ended its three-year-old banner-ad deal with Microsoft but announced that it would stop running generic banner ads, saying that “ad formats that feature social actions perform better and provide a better user experience.”

Now that advertisers were warming to Facebook, the company needed to build up its sales operation, and fast. So in March 2010,

In one study of 14 campaigns, Nielsen found that people who viewed ads displaying a friend’s endorsement were 68 percent more likely to remember the ad than were people who saw a plain display ad.

just as it overtook Google as the Web’s most visited site (according to the market watcher Hitwise), the company hired Fischer for its top sales job—luring him away from Google, where he had been Sandberg’s deputy and then her successor. One key task: attracting sales talent to Facebook’s famously geeky culture. Fischer has since expanded international offices and brought the company’s sales force to more than 500 people.

Meanwhile, that April Facebook made its most ambitious attempt yet to spread its vision: Zuckerberg announced Open Graph, a set of technologies that he called “the most transformative thing we’ve ever done for the Web.” Open Graph would integrate other participating sites with Facebook in an entirely new way. In particular, the company revealed that it was making the Like button available to any other site that wanted to add it; a

page a user “liked” on any of those sites would generate a link to be shared with friends in that person’s Facebook feed. Logged-in Facebook members arriving on a site like CNN would be able to see which stories friends had enjoyed. The personalized music service Pandora would be able to take the songs and bands a user had “liked” into account when making recommendations. Meanwhile, the things users did on those sites would be fed back into Facebook. The universal Like button has since become the centerpiece of Facebook’s plans to make marketing more of a conversation between brands and consumers (*see TR10: Social Indexing, p. 42*).

By summer, Facebook’s user base had reached 500 million and its number of advertisers, the company said, had tripled in 18 months. Many of those advertisers were small, but that is not necessarily a bad thing; Google’s ad network was built on small and medium-size businesses that like its cost-effectiveness. On Facebook, those businesses can now afford to place branding ads more efficiently. Says Fischer: “We’re bringing brand marketing to a much broader set of marketers than was ever possible before—expanding that top of the funnel.”

To underline what Facebook could do for traditional brand marketers, in September Sandberg addressed an audience of marketers and agencies at a New York conference hosted by an online-ad trade group called the Interactive Advertising Bureau. “The social graph,” she said in an expansion of Zuckerberg’s definition, “is not just connections between people but between people and the things they love.” Give people a chance to help shape your brands’ products and image, she said, and they’ll view ads as useful, engaging content, not commercial interruptions.

She came armed with figures from Nielsen, which had worked with Facebook over the past year to compare the impact of Facebook social ads and standard ads in the same campaign. In one study of 14 campaigns, Nielsen found that people who viewed ads displaying a friend’s endorsement were 68 percent more likely to remember the ad than were people who saw a plain display ad. What’s more, they were more than four times as likely to say they intended to purchase the advertised product.

MONEYBALL MARKETING

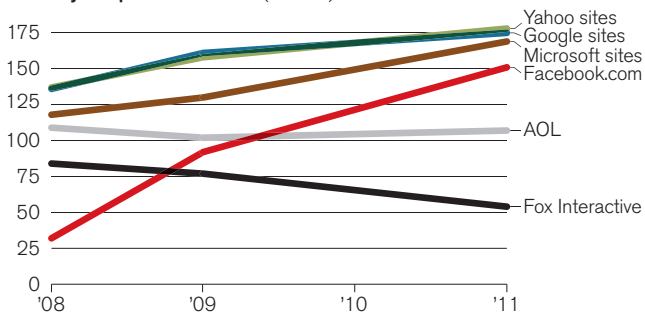
Despite Facebook’s momentum, doubts remain about whether it can persuade more big brands to open their wallets—a question that’s especially important given investors’ expectations. Maurice Lévy, CEO of the French advertising firm Publicis, told the *New York Times* this spring that he didn’t know if any business model that emerged from social media could be “as successful as people are expecting, or as successful as Google with search.” Moreover, the recession has forced brands to find cheaper ways to reach consumers—and social media is one of them. Sandberg cites company after company that has built brand value using Facebook pages and Like buttons. But, of course, those services are free.

SOCIAL GRAPHS

Facebook's audience is growing faster than those of other popular websites, but its revenues are not yet comparable to its rivals'.

People have increasingly flocked to Facebook, partly at the expense of MySpace, which is part of News Corp.'s Fox Interactive group.

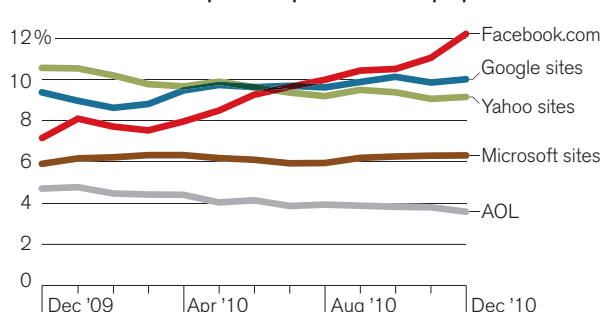
Monthly unique U.S. visitors (millions)



Source: ComScore

As more people have joined the site, it's become more useful. Now it accounts for about one-eighth of the time that people spend online.

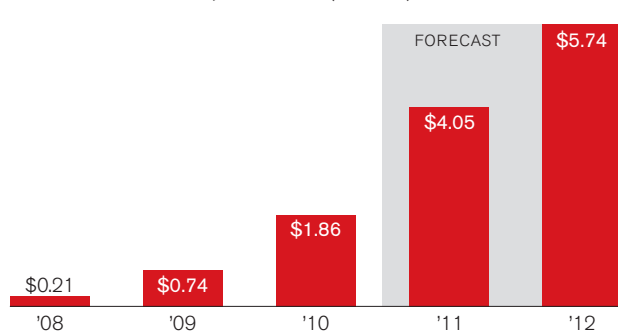
Share of online time spent at top five U.S. Web properties



Source: ComScore

These trends have made Facebook more appealing to advertisers ...

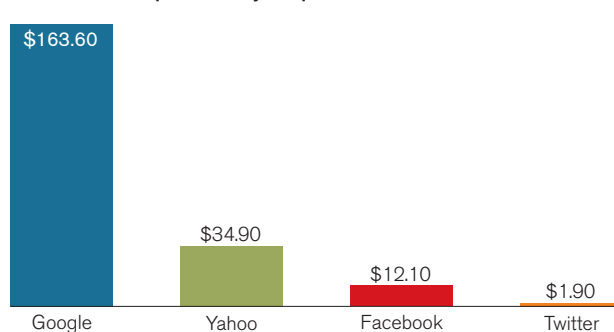
Facebook ad revenues, 2009–2012 (\$ billions)



Source: eMarketer

... but Facebook hasn't capitalized on that as it might.

Annual revenue per monthly unique U.S. visitor



Sources: Company filings; eMarketer; ComScore

Consider what Intuit did last year to promote its signature program, TurboTax. The company inserted a Like button in the application that users could click when they finished their taxes; about 100,000 people clicked either that button or the Like button on the company's Facebook page. People who saw that a friend "liked" TurboTax were four times as likely to click on a link to the product as those who saw a standard display ad. Some 30 percent of those who clicked the link bought the program, and 79 percent of them were new customers. All great for Intuit—but the company didn't pay Facebook for any of this.

"It's really the *Moneyball* era of marketing," says Cory Treffeletti, president of the San Francisco marketing agency Catalyst S+F, referring to Michael Lewis's 2003 book about how the Oakland Athletics used player data to assemble a successful baseball team on the cheap.

One potential moneymaker for Facebook would be an ad network, which would syndicate its ads to other websites in return for a cut of the revenues they generate. Google's AdSense network, for example, grossed \$9 billion last year. But the company says it has no plans for an ad network. So Facebook's biggest challenge remains coming up with new kinds of advertising that will appeal to both marketers and users.

Sandberg and Fischer admit they've not yet fully cracked that nut. If Facebook's strategy of making us all willing marketers is to do the trick, the company will have to find a way to marry the science of the social graph to the art of the advertising it's trying to replace. **tr**

ROBERT D. HOF, FORMER SILICON VALLEY BUREAU CHIEF FOR *BUSINESSWEEK*, IS A FREE-LANCE WRITER IN PALO ALTO, CALIFORNIA. HIS LAST *TECHNOLOGY REVIEW* STORY, "SEARCHING FOR THE FUTURE OF TELEVISION," APPEARED IN THE JANUARY/FEBRUARY ISSUE.

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BRIEFING

Mobile Devices

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A Computer in Every Hand

A new generation of smart phones and tablet computers is redefining computing. Impressive processing and memory capabilities, sleek touch-screen interfaces, increasingly reliable wireless data networks, sensors such as accelerometers and gyroscopes, and new applications make it possible for people to use these mobile devices in ways that weren't predicted even a few years ago.

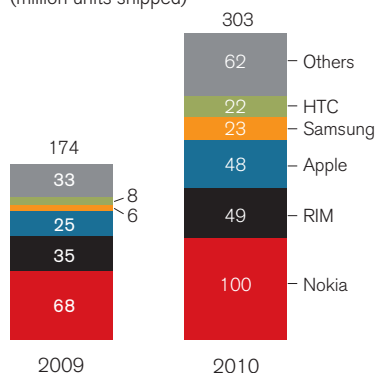
In 2010 consumers bought more than 300 million smart phones—devices that include complete operating systems, and for which advanced software can be written—plus nearly 18 million tablet computers. (Meanwhile, more than 1.1 billion simpler phone handsets with text delivery capacity reached consumers around the world, mainly in poor countries.) “Every person on earth will be carrying a smart phone before

long, and that's going to be making a lot of changes to everybody's life,” says Monica Lam, a computer scientist at Stanford who specializes in mobile-computing research.

Smart phones such as the BlackBerry and Palm have been around for nearly a decade, but the current surge of interest began with the introduction of Apple's iPhone, in January 2007. That device—whose total sales hit 100 million earlier this year—started a wave of innovation helped along by a new market in third-party applications that continues to generate novel services and forms of entertainment (see “*App Stores Make Billions, but Competition Is Growing*,” p. 77). In January, Apple sold the 10 billionth app to run on its iPhone, iPad, or iPod Touch. But these

2010: A VERY GOOD YEAR

Surging smart-phone sales
(million units shipped)



Source: IDC; figures do not add up due to rounding.

days Apple's phones and tablet computers and its proprietary iOS operating system face competition from other devices, many of which use Google's mostly open-source Android system. Android phones are now selling faster than Apple devices (see "Smart-Phone Operating Systems Control More Consumer Electronics," right). Both Apple and Android devices are increasingly controlling televisions, printers, and other electronics; future versions that include near-field communication chips might be used to control desktop PCs, too.

This mobile ascendance is truly global (see "Broadband Rises, Cellular Rules," p. 75). Whether the new mobile devices are stripped-down models in Kampala or full-strength units in San Francisco, they're providing new ways to socialize, receive news, and transact business. —David Talbot

DATA POINT

\$15.9 billion

What consumers around the world will spend on apps in 2012, according to an estimate from Gartner.

TECHNOLOGY OVERVIEW

Smart-Phone Operating Systems Control More Consumer Electronics

The heart of a mobile device is its operating system, which governs its built-in computing power as well as applications, services like e-mail, and cellular-network features such as visual voice mail. Competition among operating systems will thus shape the future of mobile technology. And because those systems can also allow control of laptops, Web TV devices, and more,

they may well become the brains controlling most consumer electronics.

The main OS technology battle pits Apple's proprietary operating system, iOS, against Google's mostly open-source Android system. But smaller competitors are growing quickly, including Hewlett-Packard's WebOS, the BlackBerry OS, and Windows Phone 7, now to be used by Nokia

OPERATOR This Palm Pre 2 runs WebOS, one of several competing smart-phone operating systems.



under a new partnership arrangement with Microsoft.

Apple's iOS—which first appeared on the iPhone and now extends to the iPad tablet and the iPod Touch—is designed to maintain tight control over what users can do with a device. It also requires them to deal with Apple's App Store.

But given the competition that's arisen, concerns that Apple's closed approach would stifle innovation were unfounded, says Gerald Faulhaber, a professor emeritus of business and public policy at the Wharton School, who researches mobile-device markets. "There is plenty of evidence of competition, and the market for operating systems is robust," he says. And this, he says, will drive development of new ideas and get new technology into consumers' hands.

What's more, the competitive market for apps—the most popular of which are available on all major operating systems—ensures that the penalties for switching from one device or operating system to another will remain low, Faulhaber says.

All the manufacturers are working toward making such switching easier. For example, HP's WebOS makes use of short-range wireless connections, allowing users to tap devices together to make one open a Web page being viewed on another. That technique can be extended to photo sharing and other data exchange.

Other manufacturers are working on similar strategies for sharing data and applications. "What users want and need is for all their devices to be connected natu-

rally together," says Jon Rubinstein, a creator of the iPod and head of HP's line of WebOS mobile devices, which the company acquired when it bought Palm in 2010. "A mobile ecosystem should really be able to give you a great user experience anywhere, whatever you are doing."

Beyond making such interoperability possible, mobile operating systems could

come to dominate all forms of computing. Rubinstein plans to bring WebOS to HP's printers and laptops. And Apple's forthcoming desktop and laptop operating system, OS X Lion, borrows interface features from iOS. Google and Apple have also installed versions of their mobile operating systems in their Web TV devices.

—Tom Simonite

INDUSTRY CHALLENGES

Advertisers Struggle Over How to Use Mobile Platforms

In theory, mobile advertising ought to be a bonanza for marketers. Millions of people use mobile devices that command their frequent attention. And ads that appear on them can even be made location-specific: Global Positioning System technology allows phone makers to tell advertisers the locations of many phones, though without corresponding personal information about the phones' owners.

In practice, however, it's tricky to deliver an effective ad on a small screen. If users do click on an ad, not only should it load properly on a mobile device, but it should send them to a website where it's easy to view and buy a product on the spot.

Google says that while mobile ads are already a billion-dollar business, that's just a start, because 79 percent of its large advertisers haven't optimized their websites for display on small screens. "Consumers want to be able to complete their transactions on mobile, so this should be a big focus for advertisers," says Michael Slinger, Google's director of mobile ads for the Americas.

And advertisers have been slow to take advantage of the location data that's available from millions of phones. Even the



CUSTOM ADS These ads for Audible.com books are specifically designed for the small screen, something most advertisers haven't mastered.

largest ad networks don't have enough in their inventories to actually send the ads best matched to people's location needs, even when it's possible to determine what those should be, says James Pearce, senior director of developer relations for Sencha, a company that provides open-source Web application frameworks for desktop and mobile devices.

In a hypothetical example, if a customer is using a mobile device to search for information about car repair, an ad for a nearby mechanic might be a good idea. But if the network doesn't have one available, that person might instead be shown something else, such as an ad for a new car—an ad that might be more annoying than useful.

DATA POINT

30 million terabytes

The total amount of mobile data traffic estimated for 2014, up from 2.3 million terabytes in 2010.

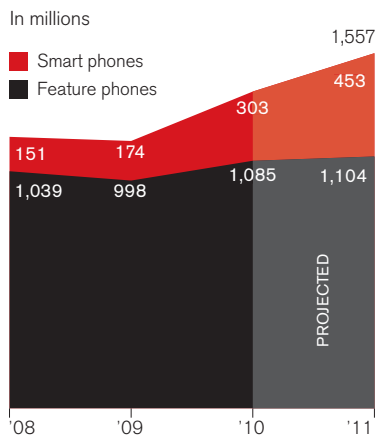
APPLE

Such problems are keeping companies from realizing the full benefits of mobile advertising, says Pearce. But ad brokers are consolidating, which might help networks build up the inventory they need to target users effectively. In December, after Google acquired AdMob and Apple acquired Quattro Wireless, the market research firm IDC estimated that the two companies controlled two-thirds of the mobile advertising market. Meanwhile, some users are broadcasting their location to their social networks—and to potential advertisers—through applications like Foursquare, which invite them to “check in” at shops and restaurants.

Advertisers can benefit from knowing where users are, but Pearce points out that simply knowing what device a person is using can be quite valuable too. (The most expensive devices, unsurprisingly, are owned by those with higher incomes.) Ultimately, he believes, mobile advertising will prove very powerful, particularly for small businesses. Such companies could get a lot of mileage out of simply providing clickable phone numbers to customers in the right locations. —*Erica Naone*

STRONG PROJECTIONS

Sharp growth is expected in 2011 for smart phones, with flat sales for simpler phones.



Source: IDC

TEXT TOOLS

Nokia's Ovi Life Tools include SMS-based educational apps like the one this boy is using.



CASE STUDY

Nokia Sets Sights on Developing World

For many people in poor countries, their next mobile device will be their first—and it's likely to be made by Nokia. The Finnish company, which ships more phones globally than any competitor, leads rivals in global sales of both smart phones and less powerful, less profitable “feature” phones. A key part of its strategy is to build new devices and services tailored to markets with minimal infrastructure.

Today, Nokia's share of the fast-growing, high-margin smart-phone market is shrinking as iPhone-like handsets take over. Sales of feature phones are roughly flat worldwide but are still growing fast in poor regions, particularly the Middle East and Africa. To tackle these markets and reach people who have never owned a phone before, Nokia is now designing products specifically for particular social and cultural needs.

“These devices necessarily have to be less complex than those in the developed world,” says Henry Tirri, who leads Nokia's

research efforts. “But they can still serve the same hunger that we have for our latest devices—needs like socializing and entertainment.”

The X1-00 phone is the latest result of Nokia's attempts to strike a balance between stripped-down, practical devices and objects of desire. The handset has a battery that lasts for 61 days on standby, a useful feature where electricity supplies are unreliable. An integrated speaker significantly louder than any on U.S. smart phones can blast out not only MP3 files

DATA POINT

58%

In an analysis by Appsfire of 1,000 iPhones, that's how many downloaded apps were free; 23 percent were paid for. The rest were preloaded.

but also FM radio, a major source of entertainment in parts of the developing world.

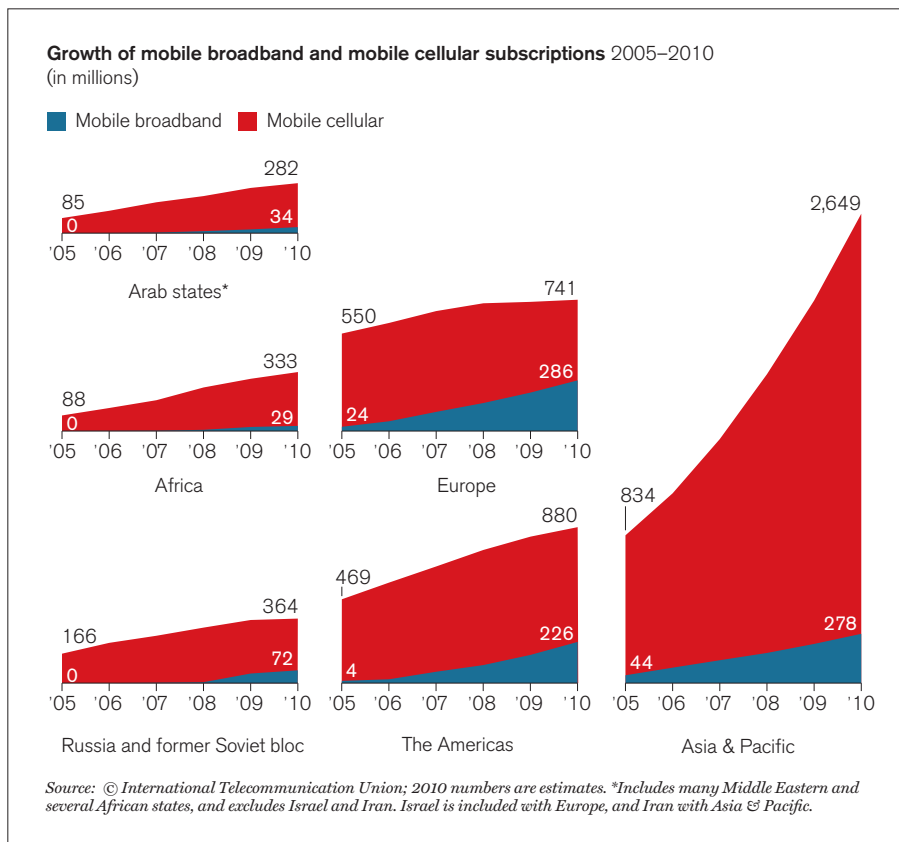
Nokia's product development is guided partly by ethnographic research that examines "market structures, livelihood activities, cultural practices, and how they operate in concert—and where a new thing like the mobile phone fits into that," says Jenna Burrell, an assistant professor at the school of information at the University of California, Berkeley. She found during her own research in Uganda that local people most valued

mobile phones because they helped them avoid traveling, which in turn saved them time and money. Nokia researchers are also working on SMS-based services similar to Internet apps and services. A Nokia service called Ovi Life Tools—available in India, China, Nigeria, and Indonesia—allows users to subscribe to SMS updates on topics like agriculture and sports. Another, Mobile Communities, lets them share text messages in groups, and send and receive Twitter-like updates. —Tom Simonite

WORLD MARKETS

Broadband Rises, Cellular Rules

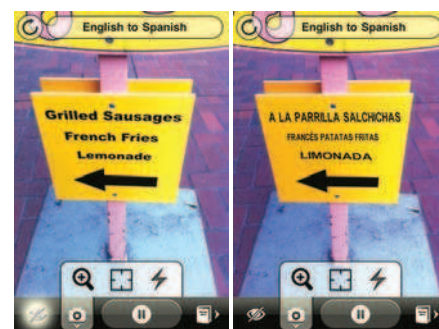
In much of the world, mobile broadband connections have grown by orders of magnitude in recent years. Still, far more people have cellular subscriptions, often on simpler feature phones. Thus text messaging, including the delivery of news and banking services, is the way most people use mobile devices for services other than voice calls.



OVER THE HORIZON

Text and Voice Translation in Real Time

The translation technology in Google's smart-phone apps is the closest thing to a universal translator today. Google Goggles, for example, extracts text from an image snapped by a user and converts it with the help of a technique called statistical machine translation, relying on a cloud server for the necessary processing power. So far it can recognize text in just five European languages and translate the text into any of those languages plus another 12. But Google is aggressively expanding into new languages, particularly those used in



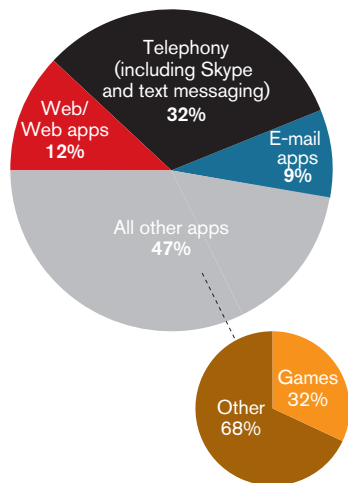
AUGMENTED REALITY Word Lens displays the Spanish translation (right) over the original English text. Other languages are in the works.

markets where mobile devices are often the only computers people own.

Augmented reality could integrate such translation services into everyday views of a foreign city. With Word Lens, from Quest Visual of San Francisco (see "A New Reality," p. 84), a user can aim the phone at a sign or document and immediately consult the display to see translated text replacing the original. Because the translation takes place inside the device and doesn't rely on

HOW WE USE THEM

People use smart phones 84 minutes daily, in categories broken down as follows:



Source: Appsfire (analysis of 1,000 iPhone users' habits in late 2010, excluding those who didn't use apps).

network connections, it's handy when traveling. So far Word Lens can translate only between Spanish and English. More languages are in the works.

Google recently launched a cloud-based app that can take in spoken phrases in any of 15 languages and synthesize translated speech in any of 23. The next frontier: translating live speech. In "conversation mode" you speak into your Android device; Google Translate will read a translation. At a January conference, Google chairman Eric Schmidt said the system "seems to work like magic." Yet it works only between speakers of English and Spanish, and accents and noise degrade accuracy. Adding languages and improving accuracy is an active area of research. —Tom Simonite

DATA POINT

7.9 billion

Number of app downloads to all mobile devices in 2010, according to ABI Research.

RESEARCH TO WATCH

Turning Your Phone into a Wallet

Technologies already exist that could allow mobile phones to function as payment devices. Near-field wireless chips can pass information to reading devices at distances of up to a few centimeters. In fact, consumers in Japan and Korea already use phones containing such chips to pay for public transit, buy snacks from vending machines, and check in to flights.

These chips are expected to appear in growing numbers of smart phones, but clever apps are needed to make payment services more attractive. For mobile payment systems to really take off, says Christina Nguyen White, a user experience designer at SapientNitro, applications will have to do more than just replace the cash part of the transaction; they'll need to incorporate the functions of other things people carry in their wallets, such as ID cards and store loyalty cards. "A digital wallet is literally taking that fat wallet out of your purse or your pocket and sticking it in a digital device," White says.

In one effort in the United States, PayPal—best known for providing online person-to-person payment—has entered into a partnership that lets its payment processing system link up with the mobile payment system offered by the startup Bling Nation. Users receive stickers containing a near-field communication chip, which they can slap on their phones to start making payments through a PayPal account. Bling Nation has signed up a variety of local retailers across the country, including coffee shops, restaurants, and gas stations.

Even if people choose to hang on to their credit cards, they still might end up paying by mobile phone at businesses that use Square, a service that brokers card payments from Apple and Android mobile devices. Sellers plug a small card-swipe magnetic reader into the device and use a downloaded app to process payments, sending Square a commission on each transaction. —Erica Naone

FIRST APP Mobile-phone payment systems emerged in Japan in 2004.





APPS HAVE IT
Consumers shop at an Apple store in Palo Alto, California.

MARKET WATCH

App Stores Make Billions, but Competition Is Growing

Everything changed in the mobile business in 2008, when Apple launched its iPhone App Store to distribute third-party applications that run on its operating system. Apps range from race-car games to GPS navigation tools, and in January, the 10 billionth one was downloaded from the store.

Apple, which collects a 30 percent commission on paid apps, earned \$1.8 billion from its app store in 2010, according to industry analyst IHS Screen Digest. More than 350,000 apps are available for iPhones and the iPod Touch, and another 65,000 for the iPad tablet.

But competition is intensifying. Google's open-source Android operating system—which runs on many devices that compete with the iPhone—has its own app store, the Android Market. Other app stores serve devices from Research in Motion (maker

of the BlackBerry), Nokia, and Microsoft. IHS estimates that Apple commanded 83 percent of the global app market in 2010, but its dominance may not last. Android devices are now surpassing Apple devices in sales. If that trend continues, Android apps will outnumber those for Apple devices by mid-2012, according to Lookout, a software security company.

App stores selling downloads also face competition from apps that run remotely over the Web. The newest Web programming standard, HTML5, “can create experiences as compelling as an app and give developers complete freedom to implement whatever business model they want,” says Jamie Hall, cofounder and CTO of Boston-based mobile social network MocoSpace. For example, HTML5 can allow sites to access a device's location and tap into its

graphics chip to display 3-D animations. The growing capabilities of the Web led market analyst ABI Research to predict last year that app downloads would peak in 2013. A gradual decline was predicted thereafter, but the firm says it still expects the business to remain lucrative. —Tom Simonite

APP STORES, STACKED UP

Apple leads in selling applications for its devices, but competitors are growing faster.

Store	2010 revenue	Growth from 2009
Apple App Store	\$1.782 billion	131.9 %
BlackBerry App World	\$165 million	360.3 %
Nokia Ovi Store	\$105 million	719.4 %
Google Android Market	\$102 million	861.5 %
Total	\$2.155 billion	160.2 %

Source: IHS Screen Digest

Phones That Rule Everything

Location technologies can serve a variety of purposes. GPS chips and location identifiers based on Wi-Fi signal strength allow people to find and map friends or colleagues. Cameras and network connections allow not only real-time photo updates but also search applications that call upon cloud resources to identify what's in the photo—and even to translate text.

Of course, smart phones can also do things like load vehicle entertainment and navigation systems and control PCs, televisions, and printers in homes and offices. And with more than 450 million smart phones expected to reach consumers in 2011, these devices' applications could evolve in ways we haven't yet imagined.

THE SOCIAL NETWORK

Services like Foursquare allow people to broadcast their location in order to meet up. Near-field communication chips and peer-to-peer software could make it possible to exchange photos and data by “bumping” phones.

A mobile-phone owner points the device toward a sign. An app translates the text and displays the new language over the image on the phone's display.

Some existing services offer text-message advertisements from nearby retailers or restaurants, chosen according to the user's location. Customized messages on displays or billboards could be a future application.





INSTANT PHOTO SEARCH

In one application of mobile photo analysis, a customer takes a photo of a product's bar code and searches for reviews and prices.

IPHONE CASH REGISTER

Square, a startup, provides a card-swiping attachment, an app for ringing up sales, and links to credit card companies, enabling retailers to accept payments on iPhones and iPads.

PAY PHONE

Devices containing near-field communication chips, which transmit ID numbers to readers within a few centimeters, can be used to make payments or check in to flights.

COMPUTING

It's Not a Game

Putting a computer on *Jeopardy!* warps the public understanding of what artificial intelligence is and how science is done.

By JARON LANIER

Watching the computer system known as Watson defeat the top two human *Jeopardy!* players of all time was fun in the short term. This demonstration of IBM's software, however, was a bad idea in the longer term. It presented a misleading picture to the public of what is known about machine and human intelligence, and more seriously, it advanced a flawed approach to science that stands to benefit the enemies of science.

There's a crucial distinction to make right away. My purpose is not to criticize the work done by the team that created Watson.

Nor do I want to critique their professional publications or their interactions with colleagues in the field of computer science. Instead, I am concerned with the nature of the pop spectacle hatched by IBM.

Why was there a public spectacle at all? Certainly it's worthwhile to share the joy and excitement of science with the public, as NASA often does. But there were no other Mars rovers to compare with the NASA rovers when they landed, and there is a whole world of research related to artificial intelligence. By putting its system on TV and personifying that system with a name and a computer-generated voice, IBM separated

it from its context, suggesting—falsely—the existence of a sui generis entity.

Contrast IBM's theatrics with the introduction of Wolfram Alpha, a "knowledge engine" for the Web that physicist Stephen Wolfram released in 2009 (see "*Search Me*," *July/August 2009*). Although the early rhetoric around Alpha was a touch extreme, sometimes exaggerating its natural-language competence, the method of introduction

was vastly more honest. Wolfram Research didn't resort to stage magic: Alpha was made available online for people to try. Stephen

Wolfram encouraged people to use his technology and compare the results with those generated by search engines like Google. Alpha proved honestly that it was something fresh, different, and useful. Comparison with what came before is crucial to progress in science and technology.

But Watson was presented on TV as an entity instead of a technology, and people are inclined to treat entities charitably. You are more likely to give a "he" the benefit of a doubt, while you judge an "it" for what it can do as a tool. Watson avoided any such comparative judgment, and the public wasn't given a window into what would happen in that kind of empirical process. Stephen

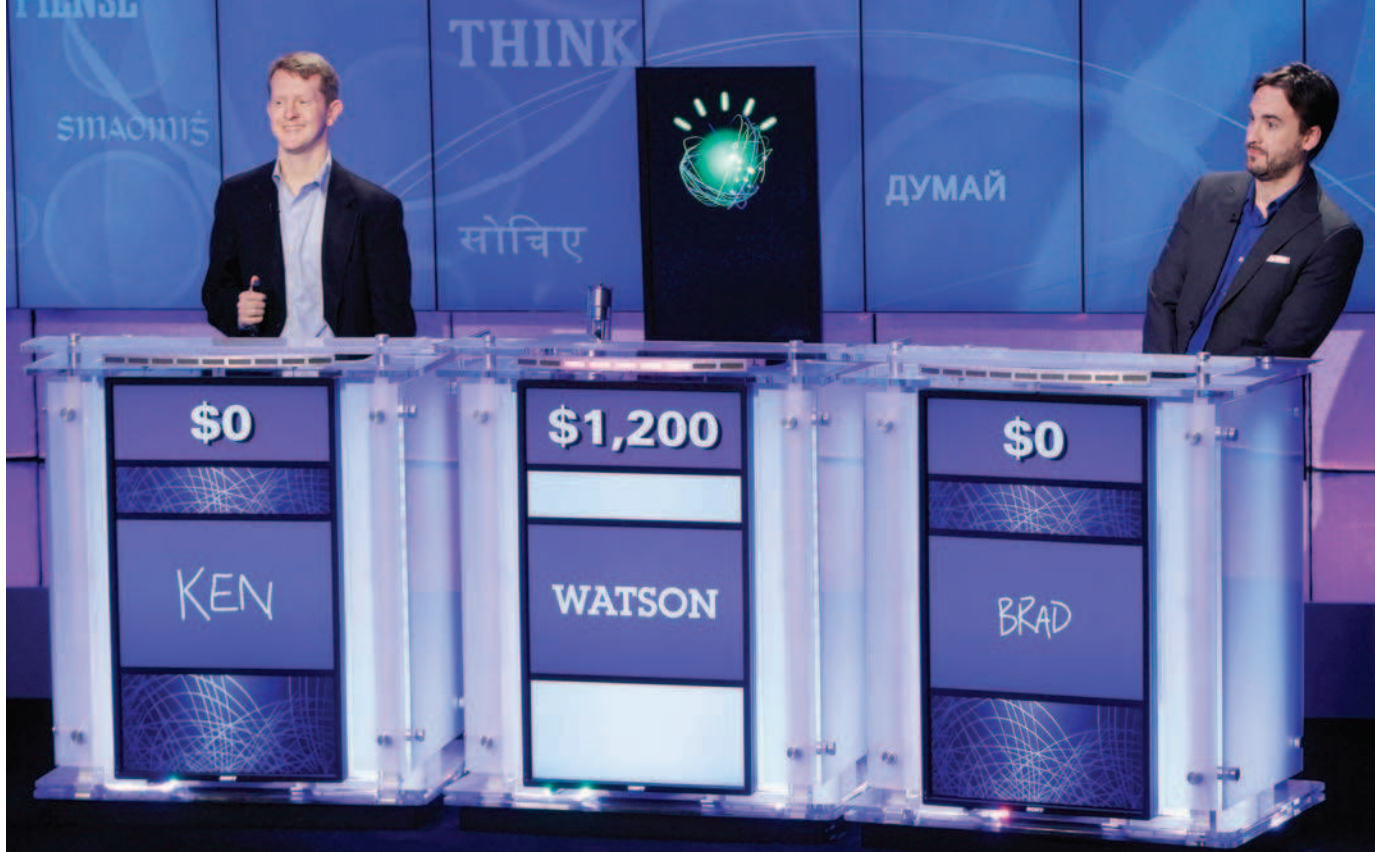
Wolfram himself, however, went to the trouble of writing a blog post comparing Watson with everyday search engines. He entered the text of *Jeopardy!* clues into those search engines and found that in many cases, the first document they returned contained the answer. Identifying a page that contains the answer is not the same thing as being able to give the answer on *Jeopardy!*, but this little experiment does indicate that Watson's abilities were less extraordinary than one might have gathered from watching the broadcast.

Wouldn't it have been better to open the legitimate process of science to the public instead of staging a fake version? An example of how to do this was the DARPA-sponsored "Grand Challenge" to create self-driving cars. By pitting technologies against each other, DARPA informed the public well and offered a glimpse into the state of the art. The contest also made for great TV. Competitors were motivated. The process worked.

The *Jeopardy!* show in itself, by contrast, was not informative. There are a multitude of open questions about how human language works and how brains think. But when machines are pitted against people, an unstated assertion is inevitably propagated: that human thinking and machine "intelligence" are already known to be at least comparable. Of course, this is not true.

In the case of *Jeopardy!*, the game's design isolates a specific skill: guessing words on the basis of hints. We know that being able to guess an unstated word from its context is part of language competency, but we don't know how important that skill is in relation to the whole phenomenon of human language.

IBM's Watson
on *Jeopardy!*
February 14–16,
2011



WHAT IS WATSON? IBM's supercomputing system beat Ken Jennings and Brad Rutter, the top two (human) contestants *Jeopardy!* has ever had.

We don't fully know what would be required to re-create that phenomenon. Even if it had been stated (in fine print, as it were) that the task of competing at *Jeopardy!* shouldn't be confused with complete mastery of human language, the extravaganza would have left the impression that scientists are on a rapid, inexorable march toward conquering language and meaning—as if a machine that can respond like a person in a particular context must be doing something similar to what the human brain does.

Much of what computer scientists were actually doing in this case, however, was teaching the software to identify statistical correlations in giant databases of text. For example, the terms “Massachusetts,” “university,” “technology,” and “magazine” will often be found in documents that also contain the term “*Technology Review*.” That correlation can be calculated on the fly to answer a *Jeopardy!* question; similar methods have proved useful for search engines and automated help lines. But beyond such applications, we don't know where this particular line of research will lead, because recognizing correlations is not the same as understanding

meaning; a sufficiently large statistical simulation of semantics is not the same thing as semantics. Similarly, you could use correlations and extrapolations to predict the next number in a given numeric sequence, but you need deeper analysis and mathematical proof to get it right every time. Goodstein sequences are sequences of numbers that seem to always go up—until eventually they revert and fall to zero. A prediction based on statistical analysis of the early phase of such a sequence would get the rest of the sequence wrong. Correlations can simulate understanding without really delivering it.

Ultimately, does the Watson show really matter? Why not let IBM's PR people enjoy a day in the sun? Here's why not: there is a special danger when science is presented to the public in a sloppy way. Technical communities must exhibit exemplary behavior, because we are losing public legitimacy in the United States. Denying global climate change remains respectable in politics; many high-school biology teachers still don't fully accept evolution.

Unfortunately, the theatrics of the *Jeopardy!* contest play the same trick with neuro-

science that “intelligent design” does with evolution. The facts are cast to make it seem as though they imply a metaphysical idea: in this case, that we are making machines come alive in our image.

Indeed, that is a quasi-religious idea for some technical people. There's a great deal of talk about computers inheriting the earth, perhaps in a “singularity” event—and perhaps even granting humans everlasting life in a virtual world, if we are to believe Ray Kurzweil.

But even if we quarantine overtly technoreligious ideas, the Watson-on-*Jeopardy!* scheme projects an alchemical agenda. We say, “Look, an artificial intelligence is visible in the machine's correlations.” A promoter of intelligent design says, “Look, a divine intelligence is visible in the correlations derived from sources like fossils and DNA.”

When we do it, how can we complain that others do it? If scientists desire respect from the public, we should expect to be emulated, and we should be careful about what methods we present for emulation. **tr**

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MEDICINE

The Cost of Life

It's time to consider price when evaluating new drugs.

By AMANDA SCHAFFER

Last year, the U.S. Food and Drug Administration approved Provenge, a treatment made by the biotechnology company Dendreon, for men with advanced prostate cancer. Clinical trials showed that Provenge extended life by an average of four months. Then came the price tag: \$93,000 for a course of treatment.

In March, Medicare, the U.S. federal program to provide health coverage to the elderly, announced that it would cover Provenge. Yet the announcement came only after a national review, a process normally reserved for complex or controversial coverage decisions. Patient advocates worried that the cost had made Medicare hesitate to pay. Weighing the price of a drug in a coverage decision would have broken a long-standing precedent for Medicare, and there's no evidence that it actually happened. But perhaps it should.

Provenge
Dendreon
\$93,000

Provenge is just one of several dizzyingly expensive medicines, especially for cancer, that have been introduced over the last few years. Gleevec, for chronic myeloid leukemia, can cost more than \$4,500 per month. Revlimid, for multiple myeloma, costs \$10,000 per month, and Avastin, for colon cancer, as much as \$100,000 per year. Neither

typical patients nor government programs nor the employers that subsidize many workers' health care can afford such costs. In 2009, health care accounted for over 17 percent of U.S. GDP, with roughly 10 percent of those dollars going to prescription medications. Trade-offs, ultimately, are inevitable.

Unlike other countries, including the United Kingdom and New Zealand, the United States has no history of taking price into account when considering approval or coverage of new treatments. The FDA's

mandate is to evaluate drugs for safety and effectiveness, not cost-effectiveness. Both Medicare and most private insurers face enormous pressure not to limit access to gold-standard treatments because of cost, though pricier drugs often come with more coverage restrictions (if Medicare limited coverage of treatments because of their cost, that would open the door for private insurers to do so as well). And most of us cringe at the thought of assigning dollar values to life. Nevertheless, we implicitly do so in many contexts—for instance, when we decide how much to spend on safety or environmental protection. “I have yet to meet the person who would say, hang the expense—there is no limit to what we should spend to save an additional life,” says Dan Wikler, a professor of ethics and population health at Harvard.

But that's when people are asked a general policy question; we think differently, of course, when it comes to ourselves or our loved ones, and that's one reason it's so difficult to control costs. There is no easy way to determine what prolonging someone's life is worth. When Peter Neumann, director of the Center for the Evaluation of Value and Risk in Health at Tufts Medical Center, asked oncologists what they consider “a reasonable definition of ‘good value for money,’” almost 50 percent said between \$50,000 and \$100,000 per additional year of life. But another study, also by Neumann, tried to get at how they would behave if they considered drug costs in a real situation (something doctors ordinarily don't do). Oncologists were asked how much additional time a hypothetical lung cancer drug would need to provide in order for them to prescribe it, assuming it cost \$70,000 more per year than the usual treatment. On the basis of their responses, Neumann estimated that the doctors implicitly valued the year at closer to \$300,000.

The United Kingdom already limits its spending for life-saving drugs on the basis of analyses by the National Institute for Health and Clinical Excellence, or NICE. The agency weighs the health benefits of a new treat-

ment against the cost and advises the government on which treatments to pay for. It generally supports approval for drugs that offer an additional year of good-quality life for less than \$30,000 to \$50,000.

The goal is to offer the population as a whole the best health care the country can afford. Money not spent on expensive drugs with little impact is money that can be spent on more broadly beneficial treatments. While the rationale is a good one, the institute's decisions are often unpopular. After reviewing the benefits of the drug Herceptin for people with HER2-positive breast cancer, the group of patients most likely to respond, NICE approved it only for use in the more advanced stages of disease. And patient groups were devastated when it recommended against Avastin, which increases life by an average of roughly four months in colon cancer patients.

A relatively strict limit on cost per month of life is unlikely to work in the United States. But a reference value—some set idea of what we consider a fair price for additional time—would be useful, even if it were not treated as a cutoff. Such a guideline would give Medicare and insurers more leverage in negotiating drug costs that today can seem almost entirely detached from the drugs' actual benefits. Pharmaceutical executives often attribute high prices to the cost of research and development, but this claim is difficult to assess because the price of a drug is not tied directly to the cost of developing it; companies use revenues from successful drugs to compensate for R&D wasted on ones that fail. And some executives admit that they simply charge what the market will bear. Demand is fairly insensitive to prices in this case, because patients desperately want access to drugs that they think could save their lives.

That means bargaining is a must. Other countries have started to negotiate with drug companies over the cost of medications, and several experts say these efforts have ultimately lowered at least some prices, though the numbers are hard to verify. While Medi-

care is legally bound to pay a drug's average sale price plus 6 percent, a congressional act to lift that requirement would be well worth the inevitable battle. In fact, this idea has already occasioned endless political fights, but the freedom to bargain is essential for the health of our economy.

The new federal health-care law takes a step toward greater rationality by funding comparative clinical-effectiveness research, which looks at the relative merits of different treatments. However, it also restricts the use of the cost-effectiveness analyses that the government will need for leverage with drug companies. (If Medicare did negotiate discounts and deals, that would make it easier for private companies to do the same, although pharmacy benefit managers and others already negotiate to some degree.) Also under the new law, Medicare can experiment with offering doctors a fixed payment to treat patients with a particular disease like breast or colon cancer, basing that payment on what the agency views as a reasonable average cost. Better cost-effectiveness information would lead to better decisions within those frameworks as well.

The real dilemma comes when a drug has clearly been shown to work but is extremely expensive. In those cases, we will need to make some hard decisions. But the one thing we can't do is keep shelling out whatever drug companies decide to charge. Says Harvard's Wikler: "Our failure to take cost into account alongside benefit in deciding which drugs and services will be publicly funded distorts our health-care budget, sends the wrong signal to pharmaceutical companies, and contributes to the unsustainable increases in the share of GDP devoted to health care in this country." In other words, though rationing may not be appealing, neither is blind overspending. And in our current system, distorted spending is already taking resources away from treatments that could save more lives at a lower cost. **tr**

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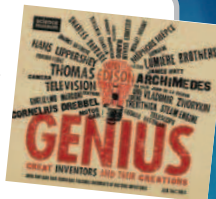
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MOBILE DEVICES

A New Reality

Applications that overlay information on smart-phone screen views will change the way we interact with the world around us.

By PAUL BOUTIN

Imagine you're on vacation in Mexico. A sunny beach looks perfect for swimming, but there's a conspicuous sign on the sand, and you don't know enough Spanish to read it. You pull the iPhone from your pocket and point its camera at the sign. When you see it on the screen, there is a difference: in English, the sign warns, "Beach closed—recent attack of shark."

This is the power of Word Lens, an iPhone app that identifies Spanish text in the live view captured by the phone's camera and translates words in a fraction of a second, replacing the originals in the same color, size, and orientation: the translated text actually seems to be in front of you, as if the sign were printed in English. (The app can also translate English into Spanish.)

It works its magic on signs, newspapers, restaurant menus, and Web pages, giving its users a feeling of familiarity with the territory that is unavailable to a tourist equipped only with a guidebook.

Word Lens is the most impressive commercially available example of the stunning potential for augmented reality—software applications that overlay computer-generated imagery on representations of the real world. Augmented reality (AR for short) became a hot topic two years ago, when demo videos flooded the Internet with examples of games, virtual shopping, and search engines that inserted digital information into live images or photos. But now AR is poised to become more than a nifty mode of entertainment. Thanks to a coming wave of more powerful, location-aware

smart phones, it will profoundly change the way we interact with our surroundings.

The range of applications goes beyond word translation. The Google Goggles app can recognize products or landmarks—say, the Itsukushima shrine in Japan—and instantly display information that Google has compiled about them. The Netherlands Architecture Institute's app draws on archival images to show buildings not as they are but as they used to be. Metaio is developing a printer-repair app that can guide a technically challenged office worker in diagnosing and fixing a recalcitrant machine.

This sort of maintenance-guide app was the original vision for augmented reality, which was named in 1992 by Thomas Caudell, then a Boeing researcher. Software that inserted relevant instructions into a real-time image viewed on a head-mounted display, Caudell realized, could help workers on a factory floor as they navigated the maze of electrical wiring for a giant airplane. The term now applies to everything from games to medical imaging to real-world guides like Word Lens.

With the best apps, "the phone isn't just a window, it's a magic wand," says Christopher Stapleton, a researcher at the University of Central Florida, who has spent more than a decade developing AR apps, including simulations for military operations in tight urban combat zones. Those applications, however, required special equipment to achieve what is now becoming possible on phones.

The possibilities are taking shape for six reasons. First, phone CPUs—the central processing units that do most of the computing work—recently reached the one-gigahertz threshold. That's not far from what is available in many little laptops; some of Intel's Atom chips for netbooks clock in around 1.5 gigahertz. Second, top smart phones also have graphics processing units (GPUs) meant for gaming and YouTube watching. Third, phone cameras are now sophisticated enough to feed abundant raw data about their environs into computer-vision algorithms. Fourth, screen resolution on mobile devices has advanced from grainy to super-slick. Fifth, wireless data networks are becoming faster and more widely available. But most important of all, smart phones have accelerometers, gyroscopes, and compasses that detect their location and orientation. That means an AR app can tell where you're standing and in which direction you're pointing the camera. Location detection is done either through GPS or by scanning for local Wi-Fi networks and matching the list of names to a database.

Word Lens, in its current form, doesn't use either location detection or a network connection. But it pushes the boundaries of handheld computing, given that optical character recognition—a trick it performs in real time—was designed for the less challenging task of reading scans of paper documents.

"We have to be able to tell a word from a tree or a face," says Otávio Good, the app's primary developer. "To do that, we run the image through a filter to remove shadows. Text is sharp, so remove whatever is not sharp. We make the image black and white, to help figure out where letters are. Still, these are blobs that may or may not be letters. Maybe that's a tree and a house, not an A and a V."

Once Word Lens has identified letters, it calculates their rotation and the perspective from which the viewer is seeing them. Then it tries to recognize each letter by consulting a library of reference font sets.

Word Lens
\$9.99 in Apple's App Store

Google Goggles
Free in the Android Market; available on Apple devices as part of Google's search app

“At that point, we have a string of letters,” says Good. “But we’re not sure what each one is. We do a dictionary lookup of this probabilistic string of letters for the closest match, if there is one.”

If there’s a match, Word Lens’s final stunt is to “repaint” the sign. “We erase the original and use the existing orientation, foreground, and background color, which may be a gradient [rather than a constant color], to put new text on top,” Good says. “That’s a

tion and translation. He resorted to some old-school assembly language programming for maximum efficiency. As a result, Word Lens on an iPhone 4 can redraw Spanish to English, or vice versa, up to 10 times per second as you move the phone around.

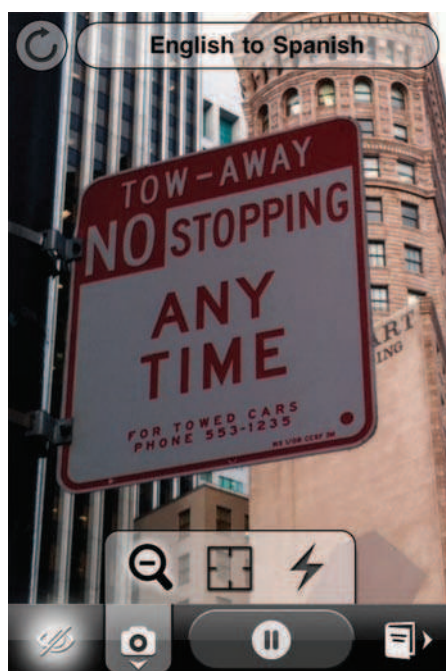
Just wait until Good can tap into an iPhone 5, or a forthcoming Android phone with a dual-core CPU and a more powerful graphics chip. When these hit the market this year, expect an even more head-spinning

phone is accurate to a few meters,” says Bruce Thomas, who directs a wearable-computing lab at the University of South Australia. He builds systems that require backpacks and headsets in order to offer AR suitable for military training, or for peacefully walking around a proposed suburban development site to see how it will look when built up. “We’re using \$3,000 sensors that can pinpoint your location to within the width of your head, and the tilt of your head to within five degrees,” he says. That increased precision lets Thomas’s system overlay imaginary buildings onto your view as you move your head around. This concoction of hardware and software costs about \$30,000. But it’s not unrealistic to think that such high-precision location detection could become possible in a handheld device. Already, in fact, the resolution on phone screens has leapfrogged ahead of the resolution in Thomas’s headset displays.

If augmented reality is to reach its mass potential, though, apps also need to be easier to build. A project at Georgia Tech is working on an open technical platform for mobile AR content. Others are working on establishing proprietary platforms; the software maker Layar, for example, builds tools that help other companies create apps. If developing apps is easy enough, the challenge for app creators won’t be technical, says Gene Becker, a Layar strategist. It will be to create “an experience that people will want to use instead of checking Twitter.”

Like GPS navigation, which in retrospect seems tantamount to a proto-AR, the best augmented-reality technologies will be those that make the miraculous seem mundane. Visualize an app that guides you to the correct shelf at the supermarket, talks you through changing a flat tire, or reminds you who the other people in the room are. Once it exists, you probably won’t want to live without it. **tr**

PAUL BOUTIN IS A FREELANCE TECHNOLOGY WRITER IN LOS ANGELES WHO ALSO CONTRIBUTES TO *WIRED* AND THE *NEW YORK TIMES*. HE REVIEWED GOOGLE’S SOCIAL-NETWORKING EFFORTS IN THE NOVEMBER/DECEMBER ISSUE OF *TR*.



AT YOUR SERVICE Unlike augmented-reality programs that show information on top of an image of your surroundings, Word Lens appears to change the surroundings themselves.

pretty straightforward computer graphics operation. It’s like using Photoshop.”

He makes it sound easy, but Word Lens wasn’t cobbled together from off-the-shelf software. Good, a former Xbox 360 programmer, found that the iPhone’s GPU was nowhere near powerful enough to perform the image-processing tricks he’d learned on the Xbox. Instead, he had to route computations through the CPU, whose single-core architecture limited his ability to run operations in parallel to speed up text recogni-

tion. It will be able to recognize more fonts and more languages, and it won’t be stumped by a sign with rust from its mounting bolts dripping down over its letters. Good also expects to reduce any visible flickering in the app. “Photorealism makes it much more effective,” he says.

That’s the litmus test for AR: can you forget that you’re looking at a computer screen? To get to that point, many applications will need more precise input than is possible on today’s phones. “GPS on a

Look, No Hands

Google's self-driving car
By ERICA NAONE

GOOGLE'S LATEST technology experiment isn't about helping you navigate the Web—it's about teaching cars to drive themselves. Exhibiting its usual boundless faith in technology, the company says it hopes its work leads to cars that are safer and more efficient. The company has logged more than 140,000 miles in seven modified Toyota Priuses, along with one modified Audi TT, in self-driving experiments, primarily around the San Francisco Bay area.

The company won't say how much it's spending on the project, but it's clear that the equipment is far from everyday: the cars are loaded with sensors that feed data to an onboard computer that, in turn, controls the vehicle.

A LIDAR LASER

Mounted on top of the car is a light detection and ranging (LIDAR) laser, a technology commonly used in police speed-detection guns. Like any other LIDAR system, it determines the distance and position of surrounding objects by sending out laser pulses and measuring how long it takes for the light to bounce back. On the Google cars, the device makes about 10 rotations per second, gathering data about objects within a circle of roughly 70 meters.

E VIDEO CAMERA

A video camera placed near the rearview mirror detects important visual cues such as changing traffic lights.

F MANUAL CONTROL

The red button instantly restores manual control of the car if the standby driver deems it necessary. A person can also grab control by turning the steering wheel slightly or tapping the brake.

D

F

E



D ONBOARD COMPUTER

A laptop computer inside the car gathers data from the sensors and controls the vehicle through its own onboard computer systems. This makes the steering wheel appear to turn on its own. Data from each driving session is transferred to Google servers for analysis, which is helpful in fixing bugs.

B RADAR

Three radar sensors in the front part of the car, and one behind, also help detect nearby objects and determine how close they are.

C POSITION SENSORS

A sensor on the left rear wheel detects small movements. This data, when combined with information from a GPS system and internal gyroscopes, helps the self-driving car calculate which direction it is facing.

demo

Photographic Manipulation

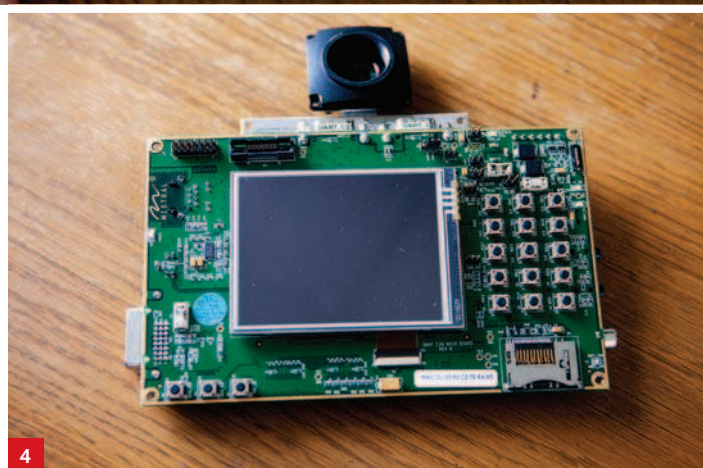
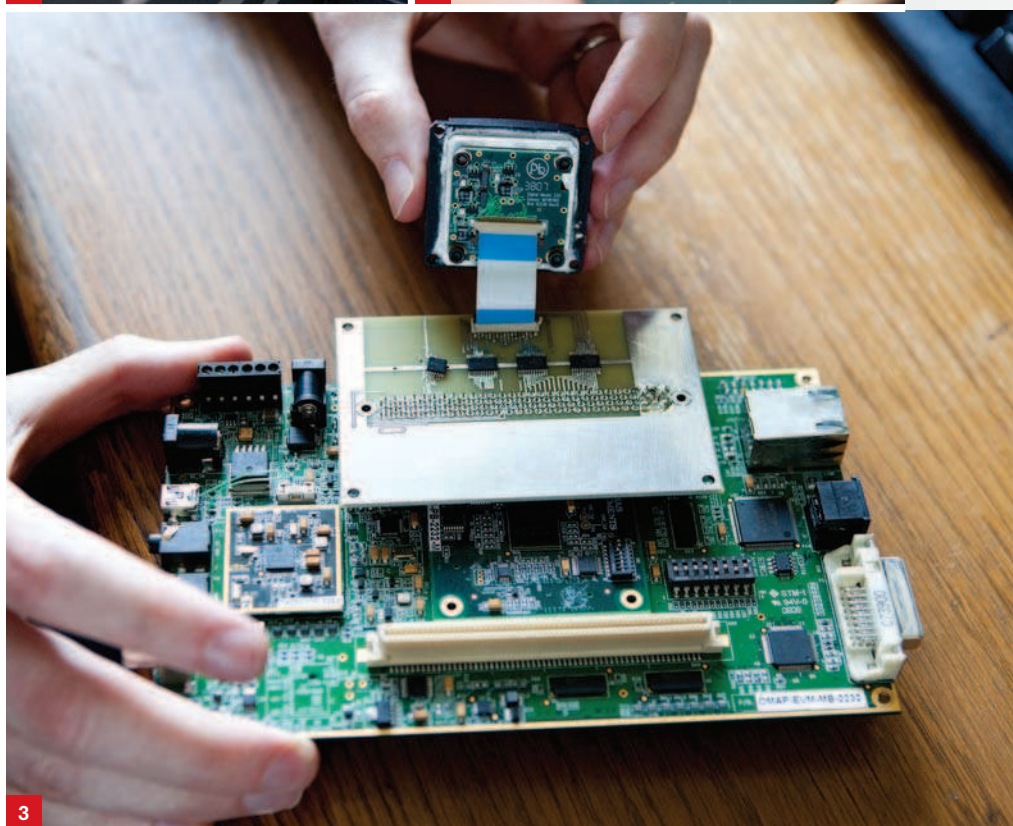
A hackable camera opens new possibilities for digital photos.

By TOM SIMONITE

David Jacobs, a graduate student at Stanford University, kneels on the floor and tosses playing cards into the air. A clunky black box with two flashes on top illuminates the cards midflight with strobing light and creates a digital photo that traces their progress through the air. Meet the Frankencamera, a hackable device made at Stanford to prove that the locked-down technology of commercial cameras is holding photography back.

Today's cameras are essentially computers with optical components, but much of that computational power is inaccessible to consumers. Manufacturers block changes to the software and much of the hardware. The Frankencamera, however, can be reprogrammed or modified with extra sensors or controls.

Marc Levoy, a professor of computer science and electrical engineering, built the device to accelerate a field called computational photography, which uses software to push the limits of today's cameras. A version is being developed to sell to a waiting list of researchers. But Levoy says he is developing the techniques to pressure camera firms to open up. "I don't want to get into the camera business," he says. "The goal is to spur industry to do this themselves."





5

1. The Frankencamera's case is carved from sheets of acrylic plastic using a laser cutter, following a design stored on a computer. Large sections are cut out to make the case's main panels; smaller pieces are glued into stacks to make some parts, such as the camera's grip.

2. Chips are soldered onto the power circuit board, which converts the electrical signals from the camera's programmable components and its image sensor, allowing them to communicate. The board was designed in the Stanford lab and made by a contract supplier.

3. The completed power circuit board is connected to the back of the Frankencamera's image sensor (held at the top of the image) and its main circuit board (bottom of the image). The main circuit board is an off-the-shelf product more typically used as a test bed for mobile phones running Google's Android operating system. Its processor (the large chip at the board's center) is more powerful than that found in most digital cameras. The Frankencamera is equipped with a version of the Linux operating system that's been customized to control camera hardware and peripherals of all kinds, from flashguns to motorized camera mounts that can be programmed to swivel and pan.

4. This view shows the reverse side of the camera's main circuit board, bearing the touch-screen LCD panel (center) that is the camera's viewfinder. The researchers are developing new ways to use such screens to control cameras.

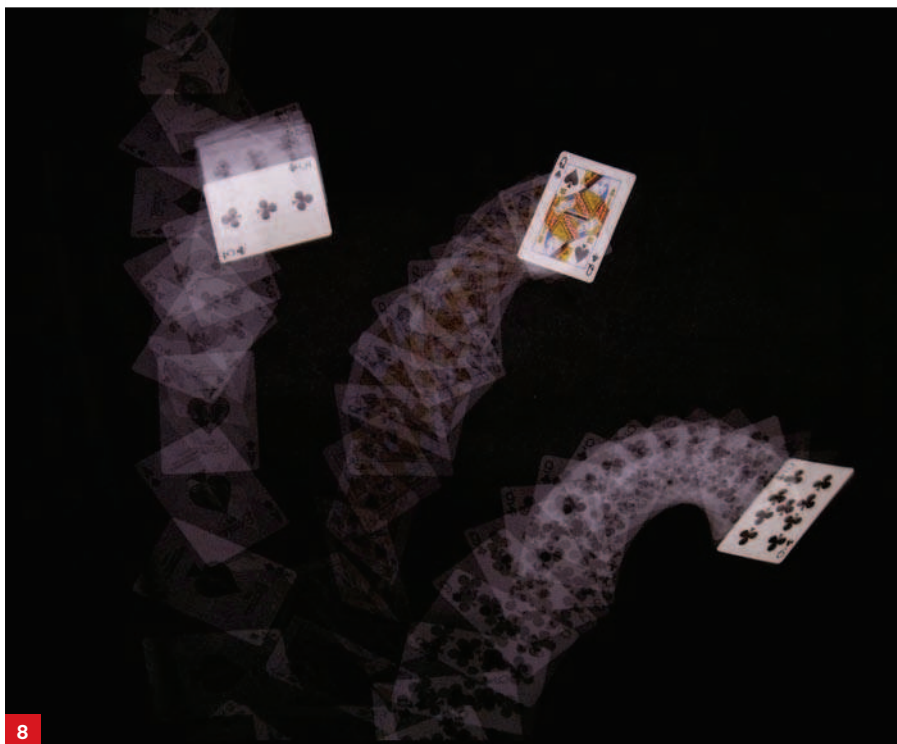
5. The electronics are fitted inside the case to complete the Frankencamera. The main circuit board connects to an electronic lens mount to control the focus and other settings of conventional lenses. Some of the wires seen here are loose cabling. The USB connector (left side of image) allows for the use of extra hardware.



6. David Jacobs, one of the graduate students working on Marc Levoy's project, prepares for an experiment by attaching a top plate with two hot shoes, used to mount and control flashguns. Conventional cameras can control multiple flash units, but they can be triggered only once, simultaneously, during an exposure. The Frankencamera can be programmed to set off up to eight flashguns at different times during a shot.

7. Jacobs throws cards into the air while a fellow graduate student presses the shutter release. He programmed the camera so that when the shutter opens, the first flashgun strobes on and off for one second. Just as the strobing ends, the second flashgun is triggered, firing once with a much brighter light than the strobe.

8. The final image. The strobing flash unit lights up the cards again and again as they move through the air. Each time they are lit up, the camera's sensor adds to its image, recording their trajectories in a series of steps. The high-powered blast from the second flash allows the Frankencamera to capture a brighter image of the cards at the end of the strobe sequence.


[www](http://www.technologyreview.com/demo)

See the Frankencamera take shape:
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MATERIALS

New Electronic Material

First speedy transistors made from an ultrathin material

SOURCE: "SINGLE-LAYER MOS₂ TRANSISTORS"

Andras Kis et al.

Nature Nanotechnology 6: 147–150

RESULTS: Researchers made high-performance transistors from ultrathin sheets of a mineral called molybdenite, which is used as a lubricant and is relatively inexpensive.

WHY IT MATTERS: Materials that are just a few atoms

thick have unusual electrical and optical properties that make them promising candidates to replace or complement silicon and other traditional materials. Single-layer molybdenite is two-dimensional, transparent, flexible, and highly conductive. The transistors are the first high-performance devices to be made from the material; this early work suggests it could be used in fast, low-power digital logic circuits as an alternative to silicon, which is reaching its limits. Molybdenite could also offer advantages for making

ELECTRIC MINERAL When peeled to make sheets just three atoms thick, this mineral, called molybdenite, is a promising material for making circuits and solar cells.



higher-performance flexible solar cells and light-emitting diodes for displays.

METHODS: Researchers manually crushed molybdenite and used tape to peel apart the crystals layer by layer until fragments just three atoms thick were left. They deposited these thin films on a substrate, added an insulating material, and used standard methods to add source and drain electrodes and a gate to make a transistor.

NEXT STEPS: The researchers will try to make devices out of other ultrathin materials in the same class as molybdenite, such as tungsten disulfide.

Skinny Superconductors

Thinner cables could lead to more efficient transmission and stronger magnetic fields

SOURCE: "COMPACT GDBA₂CU₃O₇- Δ COATED CONDUCTOR CABLES FOR ELECTRIC POWER TRANSMISSION AND MAGNET APPLICATIONS"

D. C. van der Laan et al.

Superconductor Science & Technology 24: 042001

RESULTS: Researchers have used rare earth metals to make superconducting cables that are one-tenth the diameter of existing versions and far more flexible.

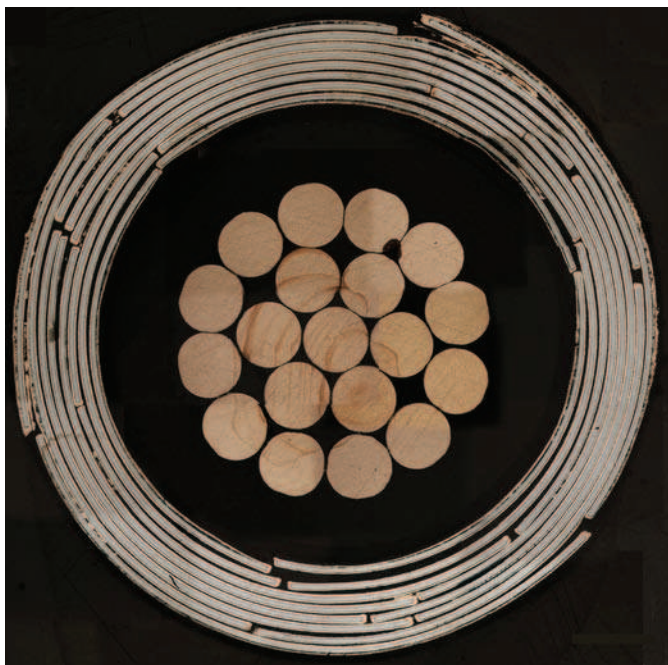
WHY IT MATTERS: Conventional superconducting

cables can carry currents about 10 times as strong as those carried by copper wires. They can also reduce energy losses in power transmission and produce extremely strong magnetic fields. But a 7.5-centimeter-thick cable structure is used to protect the superconducting material, seriously limiting its applications. The thinner cables—which are less than a centimeter wide—could be installed onboard military airplanes and ships to carry the high currents needed for lasers and other equipment. They could greatly increase the capacity of transmission cables in conduits under city streets, and they could be wound tightly to create magnetic fields far more intense than is possible today. That would be useful for applications such as particle accelerators and proton therapy, a type of radiation treatment.

METHODS: Researchers discovered that a relatively new class of superconductors based on rare earth metals could withstand much higher mechanical strain than existing superconductors. They designed cables that made use of the materials' high tolerance for compressive forces: they're wrapped in tight bends around a copper form that's much thinner than the ones in conventional cables.

NEXT STEPS: The researchers are developing versions of the cables that are even more flexible. They are also testing the cables' ability to generate strong magnetic fields.

ANDRAS KIS



TIGHTLY WOUND A cross-section of a new cable design shows superconducting ribbons wound around a core of copper wires.

INFORMATION TECHNOLOGY

Cloud Security

Researchers have found a way to watch for spies in the cloud

SOURCE: "HOME ALONE: CO-RESIDENCY DETECTION IN THE CLOUD VIA SIDE-CHANNEL ANALYSIS"

Yinqian Zhang et al.
Proceedings of the IEEE Symposium on Security and Privacy, May 2011

RESULTS: A prototype system allows companies that use cloud computing services to confirm that their data is safe from others using the same service provider. It can detect with 80 percent accuracy the presence of unauthorized processing on the same server; the rate of false positives is 1 percent. The system will notice both attackers and inappropriate data sharing.

WHY IT MATTERS: Cloud computing makes it possible to access generic processing and storage resources over the Internet. But security concerns have made many companies and organizations hesitant to use these services. Data could be stored on hardware shared with competitors, they fear, or it could even be vulnerable to malicious software actively trying to steal information. Some customers, such as NASA, have demanded that cloud providers physically isolate their data from that of other users. The problem is that until now, it's been almost impossible to verify that this is being done.

METHODS: In the past, researchers have found that attackers can steal data about a virtual machine's activities—even sensitive information such as passwords—by watching subtle clues such as how it uses shared system

resources, including the server's temporary storage system. The researchers coöpted this principle to make it work for defense. They trained a legitimate virtual machine to watch a server's cache for telltale signs of hostile virtual machines on the same server. The technique requires no modification to existing cloud technologies and no action from the cloud provider.

NEXT STEPS: The researchers are expanding the prototype to create a complete system that can run on a commercial cloud service, such as Amazon Web Services.

Low-Literacy Web Search

A form of the Web for people who can't read aims to help poor countries

SOURCE: "SPOKEN WEB: CREATION, NAVIGATION AND SEARCHING OF VOICESITES"

Sheetal Agarwal et al.
2011 International Conference on Intelligent User Interfaces (IUI), February 13–16, 2011, Palo Alto, California

RESULTS: A search engine developed by IBM researchers makes it possible to find and access information on a spoken version of the World Wide Web. A test of the interface by 40 farmers in the Indian state of Gujarat showed that it was easy to use.

WHY IT MATTERS: More than one billion people world-

wide are illiterate, most of them in poor nations. This poses a more fundamental barrier to Web use than the cost of computers and network access. For four years, a team at IBM Research India has operated a system called the Spoken Web that uses telephone numbers in place of Web addresses so that users can dial in to "upload" or listen to spoken information. Several thousand people worldwide use the service to share information such as local crop prices. However, until now there hasn't been an efficient way to search and sort through that information.

METHODS: IBM's search engine relies on speech recognition to understand the word a person is searching for—a pesticide name, for example—and to find mentions of that word on the Spoken Web. Like a conventional search engine, it can rapidly generate a list of many results, but a user cannot skim the list to choose the best result, as is possible on the text Web. Instead, the system tells the user how many results it found and suggests ways to filter that list—for example, by the name of the person who recorded a particular piece of information. This step is repeated until there are five or fewer results. That short list is read out to the user, who chooses which result to "browse" to.

NEXT STEPS: The researchers plan to roll out the system to all users of the Spoken Web. They are also working to improve the quality of the

speech recognition software involved. Most access to the Spoken Web is in Indian languages that makers of such software have not focused on before.

BIOMEDICINE

Home Heart Monitoring

An implanted sensor significantly reduces hospitalization rates for heart-failure patients

SOURCE: "WIRELESS PULMONARY ARTERY HAEMODYNAMIC MONITORING IN CHRONIC HEART FAILURE: A RANDOMISED CONTROLLED TRIAL"
William T. Abraham et al.
Lancet 377(9766): 658–666

RESULTS: An implantable wireless sensor that measures fluid pressure in the pulmonary artery significantly reduced hospitalization rates in heart-failure patients. In a study of 550 patients at 64 centers across the country, those whose physicians used data from the sensor to monitor their health were 40 percent less likely to be hospitalized in the 15 months after receiving the implant than patients whose treatment was guided by observation of traditional measures such as weight and blood pressure. The pressure-sensing device transmits data wirelessly to a computer, where physicians can access the results and adjust the patient's medication accordingly.

WHY IT MATTERS: About two million people in the United States suffer from the type of heart failure targeted in this study. In these patients, changes in fluid pressure worsen congestion, triggering fluid buildup in other parts of the body. These pressure changes typically occur weeks or months before the symptoms get worse, but because existing methods of measuring this pressure are invasive, they are often performed only during a patient's initial evaluation. The new device provides a way for physicians to monitor fluid pressure continually after a patient leaves the hospital. They can then fine-tune medications, preventing health crises that require additional hospitalization.

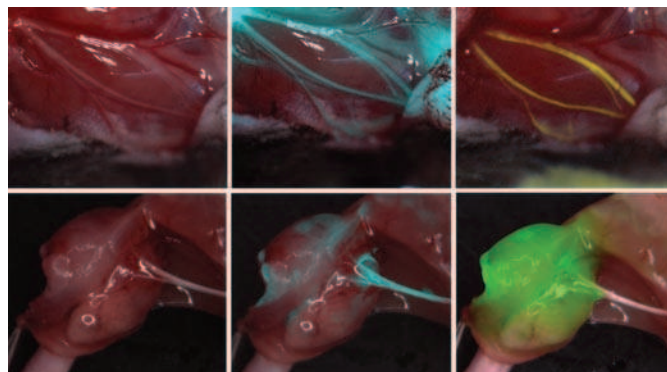
METHODS: The device is made up of two metal loops that keep it in place inside the artery and a pressure transducer that records the flow of blood through the vessel. It is implanted using a simple catheter-based procedure. The device is activated when the patient lies on a pillow with a built-in receiver. The sensor then takes a reading and transmits the data to a computer for a physician's review.

NEXT STEPS: The company that makes the device, CardioMEMS, is seeking approval from the U.S. Food and Drug Administration. It also plans to integrate the sensor's receiver into the patient's cell phone. Physicians and patients will then have instant access to pressure data.

Fluorescent Nerves

A new way to make nerves glow could protect them during surgery

SOURCE: "FLUORESCENT PEPTIDES HIGHLIGHT PERIPHERAL NERVES DURING SURGERY IN MICE"
Quyen T. Nguyen et al.
Nature Biotechnology online, February 6, 2011



NERVE MARKER Injecting mice with a nerve-specific fluorescent probe makes the nerves glow under two wavelengths of light (middle, and top right). A tumor-specific probe highlights the tissue to be removed (bottom right).

RESULTS: Researchers from the University of California, San Diego, developed a fluorescent peptide that binds specifically to nerve tissue. Two hours after it was injected into mice, all the animal's peripheral nerves glowed when illuminated with a specific wavelength of light. The effect lasted for several hours. Researchers showed that the marker also identifies nerves in human tissue.

WHY IT MATTERS: An easy way to visualize nerves should help surgeons avoid damaging them during delicate procedures. Nerve damage during surgery can lead to chronic

pain and paralysis and, in the case of prostate operations, incontinence or erectile dysfunction. Existing methods of identifying nerves label only a single tract of nerves and can take days to do so.

METHODS: To create nerve-specific probes, researchers first created a library of viruses that infect only bacteria and display different peptides, short chains of amino acids,

on their coats. They then exposed nerve tissue to the viruses, looking for the peptide that bound most specifically to peripheral nerves. Attaching a fluorescent molecule to the target peptide created a glowing marker easily detectable under certain wavelengths of light.

NEXT STEPS: Additional animal testing will be needed before the marker is ready to be tested in people. The technology has been licensed by Avelas Biosciences, a biotech startup, which is currently looking for private or industrial partnerships to develop it. **tr**

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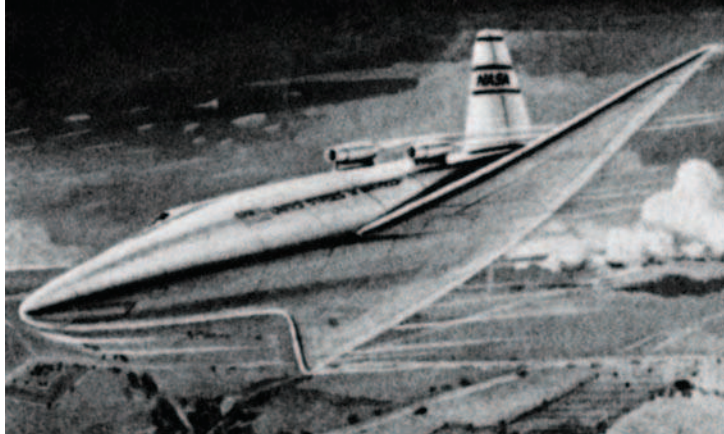
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One Small Misstep?

Questions about the merits of the space shuttle are older than the program itself.

By TIMOTHY MAHER



BACK TO THE DRAWING BOARD This NASA illustration from the shuttle's conceptual phase depicts the vehicle coming in for a landing.

As the space shuttle program winds down (the last flight is scheduled for June 28), it's fair to ask: what did we gain after several decades and roughly \$173 billion?

Certainly, the program has had its successes: shuttles have flown more than 130 missions, making possible decades of science experiments in space. Shuttle crews carried components of the International Space Station into orbit, built it, and maintained it. Crucial fixes to the Hubble Space Telescope would have been unthinkable without a vehicle like the shuttle.

On the other hand, the shuttle has kept astronauts tethered to Earth orbit. The program didn't make spaceflight less expensive, as was promised. The *Challenger* and *Columbia* disasters caused 14 deaths between them. In 2005, NASA administrator Michael Griffin said the consensus was that the shuttle, from the beginning, was "not the right path."

A lot of the potential drawbacks were apparent years before the shuttle first took flight in 1981, as evidenced by a 1971 article for *Technology Review* titled "Shall We Build the Space Shuttle?" In that piece, John M. Logsdon, a professor in the Program of Policy Studies in Science and Technology at George Washington University, laid out the conflicting and sometimes dodgy rationales for the shuttle's existence.

NASA leaders justify the shuttle in terms of a variety of national needs, but it is also true that the Agency must have an extensive and technologically challenging new program to maintain large development centers at Houston and Huntsville ... Fur-

ther, the agency needs some semblance of a future manned space flight program in order to maintain its highly visible public image.

From the moment it was conceived, the shuttle was at a disadvantage relative to the Apollo program (which had two missions to go at the time of Logsdon's writing). Where Apollo had a clear goal—to the moon and back by the end of the 1960s—the shuttle had no definite time frame or objective, and it had to please many constituencies, each with its own goals and motivations. It had to be a worthwhile vessel for science experiments. For the Pentagon's sake, it had to be plausible as a military asset. It had to capture the imagination of the American people.

The motivations underlying the decision to begin Project Apollo were preeminently political. Top priority was given to the symbolic U.S.-Soviet competition in space spectacles ... Now, there is far less fear of a Soviet threat to spur competition and innovation. There is a general questioning of the value of massive federal investments in large scale technological enterprises. NASA is being asked to demonstrate, in advance, that its plans for the next decades have some relevance to a revised set of national goals and priorities ...

A mere two years after the *Apollo 11* moon landing, the public was already starting to lose interest in space travel. Walter Mondale, then a Minnesota senator, would soon call the space shuttle a "senseless extravaganza." (However, his opposition would have little effect: four of the five spaceworthy shuttles would be constructed, at least in part, during Mondale's vice presidency under Jimmy

Carter.) Three prominent scientists—James Van Allen, Thomas Gold, and Brian O'Leary (who'd been part of NASA's astronaut program in the mid-1960s)—urged unmanned missions instead. But as Logsdon pointed out, politicians were reluctant to cede leadership in spaceflight to the Soviets.

Although public enthusiasm for new manned flight programs is now at an ebb, it is difficult to conceive of a President of the United States deciding in effect to abandon manned space activities for the next decade or more at a time when the Soviet Union is developing increasingly more complex and longer-duration earth orbital stations.

So was the shuttle the right path or not? That's debatable, but Logsdon's article suggests that by the early 1970s, the shuttle was in favor less because of its superior technology than because a lot of people had spent a lot of time thinking about it and planning for it. The idea had taken root.

*It is hard to avoid the conclusion that, whatever the merits of the shuttle, this is the wrong year for NASA to be asking for a decision to proceed with its development ... But now NASA has cranked up ... teams to study the shuttle, and it would be difficult and expensive, both for the agency and for the firms competing for the contracts, to keep those teams together for another year if the decision on the shuttle were to be deferred. Thus, although there is no strong technological or economic reason why the shuttle decision should be made at this time, organizational momentum is pressing for a decision this winter. **tr***

TIMOTHY MAHER IS *TR*'S ASSISTANT MANAGING EDITOR.

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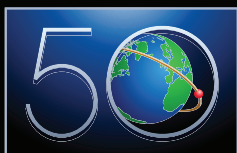
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